A Comparative Evaluation of Fence Count, Mark-Recapture and Bendix Sonar Estimates of Salmon Escapements in the Keogh River, a Variable-Flow Coastal B.C. Stream

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A COMPARATIVE EVALUATION OF FENCE COUNT, MARK-RECAPTURE AND BENDIX SONAR ESTIMATES OF SALMON ESCAPEMENTS IN THE KEOGH RIVER, A VARIABLE-FLOW COASTAL B.C. STREAM

by

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ABSTRACT

Johnston, N.T., J.R. Irvine, and C.J. Perrin. 1986. A comparative evaluation of fence count, mark-recapture, and Bendix sonar estimates of salmon escapements in the Keogh River, a variable-flow coastal B.C. stream. Can. Tech. Rep. Fish. Aquat. Sci. 1453: 44 p.

The cost, reliability, accuracy, and precision of mark-recapture and Bendix side-scan sonar estimates of spawning escapements were compared against fence counts between 26 July and 5 December 1985 for pink, coho, and chum salmon in the Keogh River, a highly variable-flow B.C. coastal river.

A double-cabled temporary counting fence was operated after the removal of the B.C. Fisheries Branch counting fence on 13 September. A total of 33,921 pink, 993 coho, and 196 chum salmon were enumerated. After the removal of hatchery brood stock and tagging mortalities, the known escapements to the river were 32,609 pink; 991 coho; and 196 chum salmon. The temporary counting fence operated 93% of the time after 13 September, at flows up to 21.6 $m^3.s^{-1}$ (765 cfs) during the autumn leaf-fall. Non-operational periods resulted from hardware failures in the cable suspension as a consequence of excessive accumulation of debris on the fence during periods of unattended operation; the fence itself was not damaged. The fence was operated at high flows by having cleaning crews present 24 h a day. The temporary fence was adequately cleaned from shore by a single person by briefly submerging the cable; cleaning frequency varied with discharge. Area-under-the-curve estimates of escapements based on 3 and 7 day counting intervals had poor accuracy and precision.

We marked 3,214 pink salmon (9.9% of escapement) with numbered spaghetti tags or opercular punches and recovered 6,459 carcasses of which 709 were marked. Tag loss was 5.2% and was readily identified. Time-stratified (Schaefer) estimates of pink salmon escapement were 7.1% and 1.4% below known escapements for estimates which included and excluded fence-caught dead respectively. Simple Petersen estimates based on cumulative recoveries underestimated known pink escapements by about 10%. All mark-recapture estimates of pink salmon escapements had good precision (CV about 8%). Mark-recapture estimates for coho and chum salmon were less accurate and less precise because of the small numbers of tag recoveries. Tag recovery surveys could be made about 75% of the time.

Bendix side-scan sonar estimates of total salmon escapements greatly exceeded known escapements. It is likely that discharge-dependent turbulence at the counting site generated spurious counts. The sonar unit was effectively unusable during much of the pink salmon run because of the milling of fish in the beam path and the difficulty in calibrating machine counts to oscilloscope counts; counts were made 70% of the time. The precision of the estimates was slightly poorer than the other methods.

Operating costs in man-days of labour per day averaged about 2.4 for the temporary fence, 1.7 for the mark-recapture method, and 0.2 for the side-scan sonar. Capital costs were greatest in dollars for the sonar but slightly greater in man-days of labour for the temporary fence, and least in both dollars and labour for mark-recapture.

RESUME

Johnston, N. T., J. R. Irvine, and C. J. Perrin. 1986. A comparative evaluation of fence count, mark-recapture, and Bendix sonar estimates of salmon escapements in the Keogh River, a variable-flow coastal B. C. stream. Can. Tech. Rep. Fish. Aquat. Sci. 1453: 44 p.

Le coût, la fiabilité, la justesse et la précision d'estimations par marquage-recapture et sonar Bendix à balayage latéral des remontées de saumons rose, coho et kéta ont été comparés aux mêmes paramètres du dénombrement par barrières. Les essais ont été réalisés du 26 juillet au 5 décembre 1985 dans la rivière Keogh, un cours d'eau côtier à débit très variable de la Colombia-Britannique.

Une barrière de dénombrement temporaire à câble double a été utilisée après l'enlèvement, le 13 septembre, de la barrière de dénombrement de la direction des pêches de la Colombie-Britannique. En tout, 33 921 saumons roses, 993 saumons coho et 196 saumons kéta ont été dénombrés. Ces valeurs s'élevaient respectivement à 32 609, 991 et 196 après soustraction des géniteurs de pisciculture et des poissons tués par le marquage. La barrière de dénombrement a fonctionné pendant 93% du temps après le 13 septembre, ceci à des débits pouvant atteindre 21,6 $m^3.s^{-1}$ (765 $pi^3.s^{-1}$) au cours de la chute des feuilles d'automne. Les périodes de non utilisation ont été causées par des bris mécaniques de la suspension des câbles résultant d'une accumulation excessive de débris sur la barrière pendant les périodes où celle-ci n'était pas surveillée; la barrière elle-même n'a pas été endommagée. La présence de préposés 24 h par jour a permis d'utiliser la barrière pendant les périodes de forts débits. La barrière temporaire pouvait être adéquatement nettoyée par une seule personne située sur la rive qui submergeait brièvement le câble. La fréquence de ces nettoyages était fonction du débit. Les estimations des remontées par surface sous la courbe obtenues à partir d'intervalles de dénombrement de 3 et 7 jours étaient peu justes et précises.

Nous avons marqué 3 214 saumons roses (9,9 % de la remontée) à l'aide de marqueurs " spaghetti" numérotés ou de perforations des opercules et récupéré 6 459 carcasses dont 709 avaient été marquées. La perte de marqueurs s'est élevée à 5,2 % et était facilement identifiable. Les estimations par stratification temporelle (Schaefer) des remontées de saumons roses étaient respectivement inférieures de 7,1 % et de 1,4 % aux valeurs connues correspondant aux estimations incluant et n'incluant pas les poissons morts pris dans la barrière. Des estimations simples de Petersen basées sur les récupérations cumulatives sous-estimaient d'environ 10 % les remontées connues de saumons roses. Toutes les estimations par marquage-recapture des remontées de saumons roses présentaient une bonne précision (CV d'environ 8 %). Les estimations par marquage-recapture des saumons coho et kéta étaient moins

justes et moins précises à cause du petit nombre d'étiquettes récupérées. Il a été possible d'effectuer des relevés par récupération d'étiquettes environ 75 % du temps.

Les estimations par sonar Bendix à balayage latéral des remontées totales de saumons étaient de beaucoup supérieures aux valeurs connues. Il est probable que la turbulence, dépendante du débit, au lieu de dénombrement ait été la cause d'importants faux dénombrements. Le sonar s'est avéré inefficace durant une partie de la remontée des saumons roses à cause du passage répété des mêmes poissons dans le faisceau et de la difficulté d'étalonner les dénombrements de l'appareil avec ceux de l'oscilloscope; des dénombrements ont été effectués pendant 70 % du temps. La précision de ces estimations était quelque peu inférieure à celle obtenue avec les autres méthods.

Les coûts d'exploitation en jours-hommes par jour d'élevaient en moyenne à environ 2,4 pour la barrière temporaire, 1,7 pour le marquage-recapture et à 0,2 pour le sonar à balayage latéral. Les coûts d'immobilisation étaient les plus élevés dans le cas du sonar et les coûts en jours-hommes étaient légèrement supérieurs dans le cas de la barrière temporaire. Les coûts en personnel et en immobilisation les plus faibles étaient ceux du marquage-recapture.

INTRODUCTION

RATIONALE

The determination of spawning stock numbers ("escapement") is a fundamental problem in the management of Pacific salmon. Escapement data are important in establishing fisheries management policies (e.g., Pearse 1982) as well as the management of specific salmon stocks. Waldichuk (1984a) and Walters (1984) discussed the numerous management uses of escapement data. At the operational level, many salmon fisheries are managed to regulate escapement since escapement is one of the few variables affecting salmon production that can be altered by the manager (Walters 1984). At the strategic level, comparisons of management policies (e.g., Walters 1975; Walters and Hilborn 1976) frequently utilize stock-recruitment relationships which are derived from escapement data.

Annual escapement estimates are made for more than 1800 B.C. salmon streams. It is widely recognized, however, that these data vary considerably in accuracy and precision because of differences in the techniques used and because of the varying conditions under which the estimates are made. The reporting system may introduce large inaccuracies since escapement has generally been recorded only as an abundance class. Such measurement errors have significant effects on the estimation of optimal escapements (Ludwig and Walters 1981; Walters and Ludwig 1981), and could result in a 25-30% loss in the average long-term yield from the stock (Symons and Waldichuk 1984). As a consequence of the "errors in variables" problem (Walters and Ludwig 1981), assessments of the accuracy of estimates of spawners and recruits are essential (Ludwig and Walters 1981).

In the Pearse Commission on Pacific Fisheries Policy (Pearse 1982) it was indicated that there is a strong need for new and consistent methodologies to improve estimates of salmon escapements to British Columbia streams. Similarly, Symons and Waldichuk (1984, p.21) recommended that "research on the accuracy and cost of various methods for monitoring escapement should be undertaken as soon as possible". Although numerous techniques exist for estimating salmon escapements (Cousens et al. 1982), there are few published comparisons of the relative accuracy, precision, and cost of the various methods, nor is it clear which methods are feasible under the extremely variable flow regimes characteristic of many B.C. salmon streams. Comparisons between methods are needed to improve the accuracy of estimates and to facilitate the standardization of methods.

To assess the precision of escapement estimates for all B.C. salmon streams for which escapements are recorded would be a formidable task. The concept of the index stream "in which salmon escapements are measured and used to estimate or predict escapements to nearby and similar streams located in the same drainage basin or biogeoclimatic zone, in which escapements are not directly measured" (Waldichuk 1984a, p.ix) has been suggested to improve the accuracy and precision of escapement data, or at least to provide general trends in stock size (Waldichuk 1984b). The validity of the index stream concept depends on whether escapements within a regional cluster of spawning stocks are highly correlated through time and whether stocks within a cluster have similar production parameters (Walters 1984). An examination of the

existing data suggested that the principal objectives of a pilot stream indexing program should be: (1) to determine whether spawning stock sizes are correlated over time; (2) to provide a set of test locations for the assessment of routine survey procedures; and (3) to provide tests of alternative methods for obtaining accurate escapement estimates (Walters 1984).

STUDY SITE SELECTION

Waldichuk (1984b) presented criteria for the choice of a stream indexing study site. The criteria included species present, access, existing escapement and smolt count data, stream size, catch data, and synchrony in stock fluctuations. Using the above criteria, Hourston (1985) recommended the Port Hardy area of Statistical Area 12 as the site of an initial stream indexing program. Walters (1984) identified potential index streams in Areas 12, 13, 14, 23 and 25 based on their contribution to total escapement, correlations with other stocks, and proximity to existing monitoring facilities. Irvine (1985) also identified potential study sites in Areas 12, 13, 14, and 23 by considering access, run size, existing fish counting facilities, confounding perturbations, flow stability and synchronous fluctuations with other stocks.

The Port Hardy region of Area 12 was chosen as the site for a pilot stream indexing program. It was the only area common to the above analyses, and it offered important advantages including an existing counting fence on the Keogh River, significant runs of pink (Oncorhynchus gorbuscha) and coho (O. kisutch) salmon contributing to a mixed fishery, good access, evidence of interstock correlations in spawning stock size, and a number of relatively small streams that could be fenced. The Keogh River was chosen as the site to commence the study because of the existing fish counting fence (Mottram 1977) and because of the extensive background data relating to salmonid production in the river (Ward and Slaney 1979; Slaney et al. 1980; Smith and Slaney 1980; Perrin and Johnston 1985).

OBJECTIVES

The necessity for comparisons of the accuracy and precision of different methods of estimating salmon escapements, both as a part of the general improvement and standardization of escapement estimation methodologies as well as a part of a stream indexing program, has been indicated above. A major objective of the work reported here was, therefore, to compare techniques as well as to initiate accurate escapement counts in a potential index stream.

Counts of fish migrating past a counting fence are generally considered to be the most accurate method of determining the run sizes of spawning salmon. Under suitable conditions counting fences can provide an exact enumeration of escapement, hence they are the standard against which other methods are frequently evaluated. However, the operation of counting fences in small coastal rivers throughout the period of adult salmon migration is difficult because of the rapid flow increases and heavy debris loads associated with freshets during autumn rains, which pose the risk of wash-out. Moreover, the necessity for in-river cleaning of debris from the fence may pose unacceptable risks to personnel. A complete census of spawning escapements requires that the fence operate under high discharge and high

debris load. A second major objective of this study was, therefore, to design and operate a temporary counting fence capable of fishing under variable flow conditions when the existing permanent fence would be inoperable.

Mark-recapture techniques are often employed to estimate escapement but rarely is it possible to assess their accuracy. In this study we evaluated the accuracy and precision of mark-recapture techniques to estimate salmon escapement using counts obtained at the fence as a standard.

In many rivers it may not be feasible or practical to utilize counting fences to enumerate upstream migrating salmon, and access may not permit mark-recapture techniques to be used. For these reasons, various electronic methodologies are being investigated to enumerate migrating fish. Sonar fish counters have been successfully used in Britain (Braithwaite 1971), Alaska (King 1984) and Washington state (Hendershot et al. 1984). The side-scan salmon counter produced by the Bendix Corporation in consultation with the Alaska Department of Fish and Game has probably been used more often than any other acoustic method. However, to our knowledge it has always been used in large rivers in which it has not been possible to have all migrating fish swim through the sonar beam. It was therefore decided to evaluate a Bendix side-scan salmon counter in the Keogh River and to install the unit so that all migrating salmon were required to swim through the beam.

The specific objectives of the study were:

(1) to count upstream migrating salmonids in the Keogh River between 26 July and 15 December by operating the existing permanent fish counting fence and a temporary fish counting fence;

(2) to design and operate a temporary fish counting fence capable of operating under high flow conditions in the Keogh River;

(3) to determine the feasiblity of estimating salmon escapements in the Keogh River using mark-recapture techniques;

(4) to determine the feasibility of estimating coho salmon escapement to the Keogh River during high flows using a Bendix side-scan salmon counter;

(5) to compare the reliability, accuracy, precision, and cost of fence counts, mark recapture techniques and a Bendix counter;

(6) to establish the run timings and other biological characteristics of spawning salmonids in the Koegh River by subsampling migrating fish for size, sex, maturity, and age and by mapping spawning areas.

MATERIALS AND METHODS

SITE DESCRIPTION

The Keogh River (RAB number 92-1000) is a small coastal river on northeastern Vancouver Island at about 50.6°N latitude and 127.4°W longitude. The river has a watershed of 129 km^2 and flows northeasterly for 32 km from

the Vancouver Island mountain range to enter Queen Charlotte Strait near the Port Hardy Airport (Fig. 1). River discharge is highly variable (0.1-225 $m^3.s^{-1}$) with flow patterns being strongly influenced by precipitation occurring as rain during the fall-winter period (Mottram 1977).

The river substrate is primarily a gravel and cobble matrix. Water depths and wetted areas vary considerably with flow, but riffles, pools, and runs account for about 41, 22, and 37 per cent of the river length (Ward and Slaney 1979). Riparian vegetation is dominated by western hemlock (Tsuga heterophylla), western red cedar (Thuja plicata), sitka spruce (Picea sitchensis) and red alder (Alnus rubra). About 35% of the watershed has been logged within the last 30 years (Perrin and Johnston 1985). More detailed descriptions of the river and its characteristics can be found in Ward and Slaney (1979), Smith and Slaney (1980), and Perrin and Johnston (1985).

Estimates of spawning escapements for pink and coho salmon have varied considerably over the last 20 years (Fig. 2), and in recent years have ranged from 2,000 (odd year) to 70,000 (even year) pinks and 200-1,000 coho. Estimates of chum (O. keta) salmon escapements have declined from a few thousand in the mid 1960's to none seen in recent years. The Keogh River also supports an important steelhead (Salmo gairdneri) sports fishery with 200-2,200 wild and up to 2,000 hatchery fish returning to the river each year (B. Ward, Fisheries Research Section, MOE, pers. comm.). Resident and anadromous cutthroat trout (S. clarki), anadromous Dolly Varden char (Salvelinus malma), sculpins (Cottus asper and C. aleuticus), lampreys (Entosphenus tridentatus), three-spined sticklebacks (Gasterosteus aculeatus), and kokanee (O. nerka), also occur.

All enumeration and tagging were conducted at the site of the B.C. Fisheries Branch steelhead counting fence (Mottram 1977) which is about 300 m upstream of the river mouth. The most salient feature of the fence (Fig. 3) is a 3 m wide sill or apron which extends across the river and has an abutment and trapbox at either end. The downstream edge of the sill is about 0.5 m above the river bottom. When the fence is operating, stop logs are used to produce a low head of water which is directed through the two upstream migrant trap boxes. A pool extends about 30 m upstream from the sill and is crossed by a Bailey bridge about 20 m upstream of the fence. A log boom trash deflector extending across the river immediately upstream of the Bailey bridge trapped much of the large floating debris. The river channel is deepest along the east bank both above and below the sill, with the result that most upstream migrating fish are caught in the east trap box. Boulders have been placed below the sill to reduce scouring and a wing dam extending from the west bank about 15 m below the sill forces the river flow along the east bank at low discharge. At high flows the area below the sill is a violent riffle with a series of large standing waves extending from the sill to the wing dam.

The fence site is tidal and water level fluctuations of about 0.7 m may occur on extreme tides.

STREAM FLOW AND TEMPERATURE MEASUREMENTS

Stream flows were estimated from water level measurements made at the old pumphouse, which is 1.3 km upstream of the fence site and beyond tidal influences (Fig. 1). Water levels were determined with a Leopold and Stevens

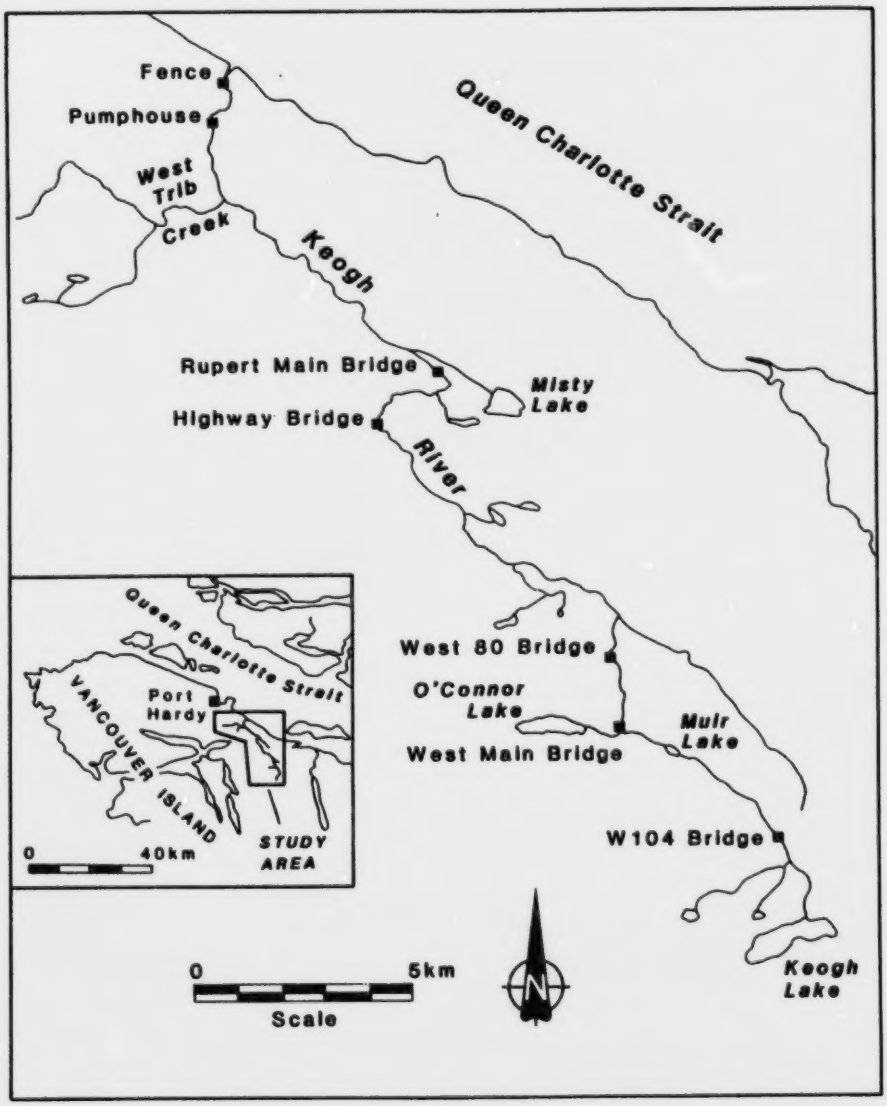

FIGURE 1. A map of the Keogh River, British Columbia showing geographical features mentioned in the text.

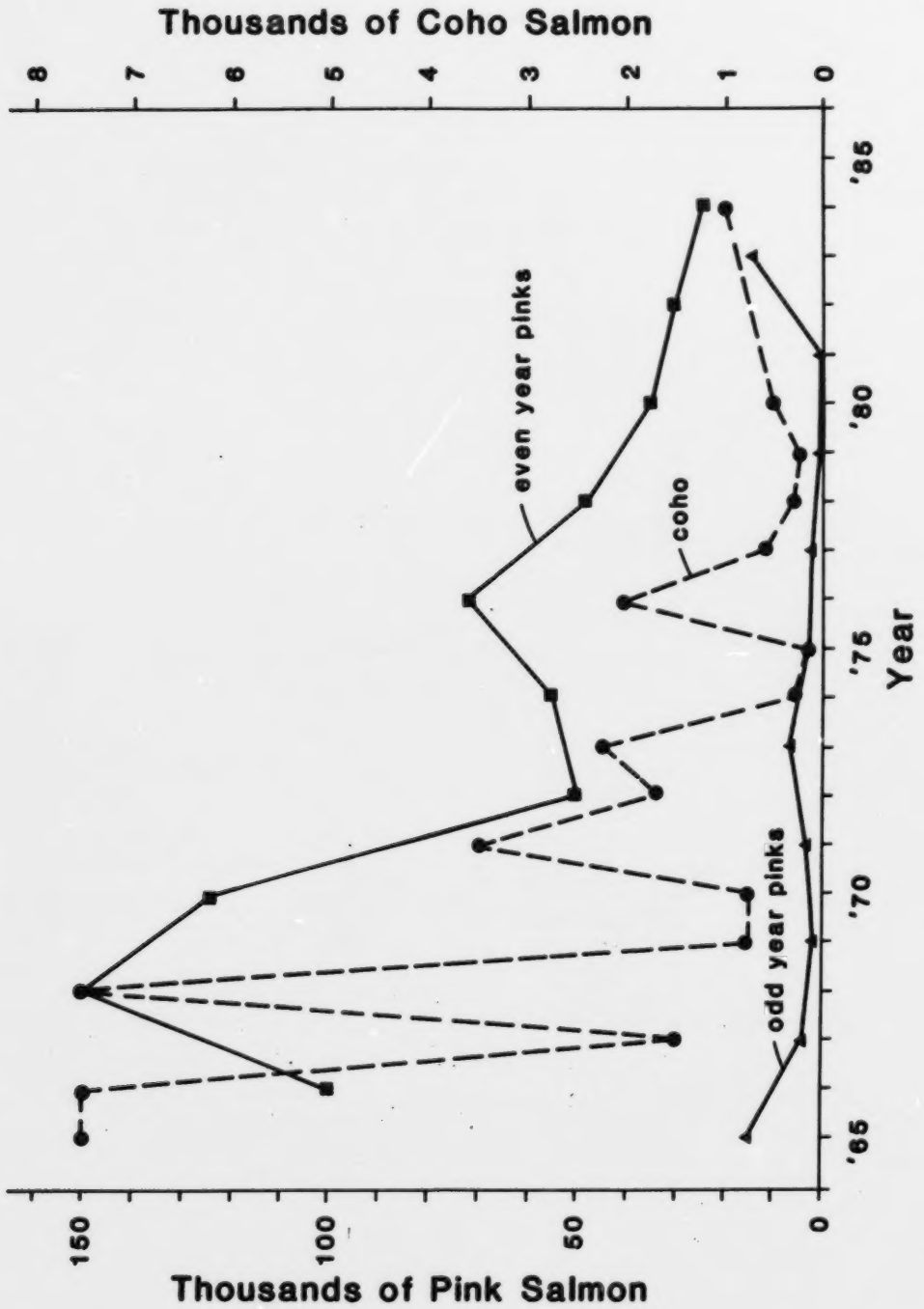

FIGURE 2. Spawning escapement estimates for pink and coho salmon in the Keogh River, 1965 - 1984 (G. Vardy, D.F.O., Port Hardy, pers. comm.).

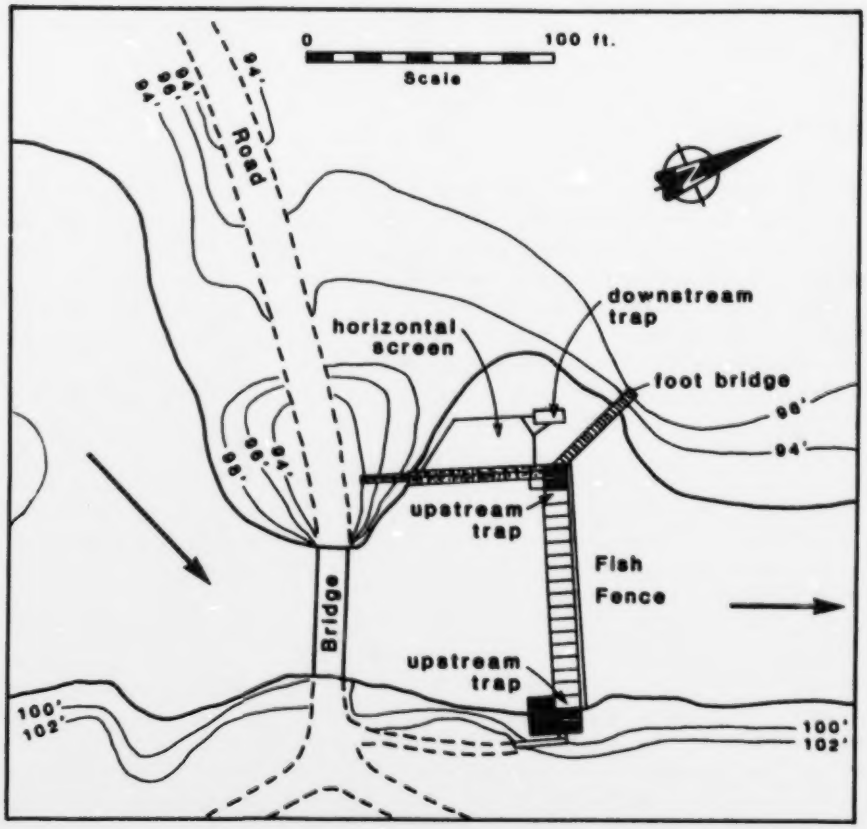

FIGURE 3. A map of the site of the Keogh River fish counting fence, showing the B.C. Fisheries Branch permanent fence (after Mottram 1977).

Model F water level recorder. A calibration curve for calculating stream flow was determined from periodic measurements of stream flows (Perrin and Johnston 1985).

Water temperatures were measured continuously at the fence site using a Ryan Model J-90 submersible thermograph which was calibrated weekly with a mercury thermometer.

FENCE OPERATIONS

The B.C. Fisheries Branch counting fence (the permanent fence) was operated from July 26 to September 12, 1985, when it was removed and replaced by a temporary fence which was operated until December 5. During the operation of the permanent fence, river flows were at extremely low, unseasonable levels. Consequently, stop logs were installed to direct most of the river flow through the east trap box and the west trap was not used. During this period water levels below the fence were usually about 0.5 m below the sill height except at the highest tide levels. To assist fish moving into the trap box it was necessary to add baffling to the trap box raceway and to construct a four step fish ladder (about 1.2 m wide by 3.5 m long) up to the sill. As few fish entered the trap box during the operation of the permanent fence, it sufficed to empty the trap box once a day, in the early morning. Fish were removed from the trap box by dip-netting after closing the trap entrance. Fish were identified, counted using hand tallies, and released above the fence; other information was taken as described below.

The temporary fence had several features to permit its safe operation under freshet conditions and yet yield a complete-as-possible enumeration. The temporary fence was designed to have a greatly increased sieving surface (166 m^2 as compared to about 27 m^2 for the permanent fence) which was inclined at a low angle to the water surface to reduce the accumulation of debris on the fence while still presenting an impassable barrier to fish passage. A cabled support system enabled the fence to be self-cleaning. By submerging the downstream edge of the fence using on-shore winches, leaves and other debris which had accumulated at the front of the net were washed off.

The temporary fence consisted of two net barriers attached to the sill by their upstream ends and suspended from overhead cables crossing the river (Fig. 4); the existing trap boxes were used. The main net was 22.8 m wide at the sill and extended 7.3 m downstream, with side and front panels 1.2 m in height. It was fabricated from braided, knotless, 210/42 nylon-twine netting (Redden Net Co.) of 75 mm stretch mesh size hung on 10 mm gillnet corkline (Towns Fishing Supplies) at a ratio of 1.25 (net) to 1 (line). The body of the net was divided into panels by 10 mm nylon corkline running from the sill to the front panel topline. The upstream end of the net was attached to the sill by wrapping the net around 5 cm x 20 cm lumber which was attached to the sill with 20 cm galvanized spikes. The downstream end of the net was suspended from an overhead cable by 5 mm galvanized chains which were shackled to the cable and which connected via an adjustable 5 mm carbine clip to a piece of 9.5 mm nylon corkline attached to the net; the length of the suspending chain could be adjusted by moving the carbine clip. This net was the primary barrier to fish movement upstream.

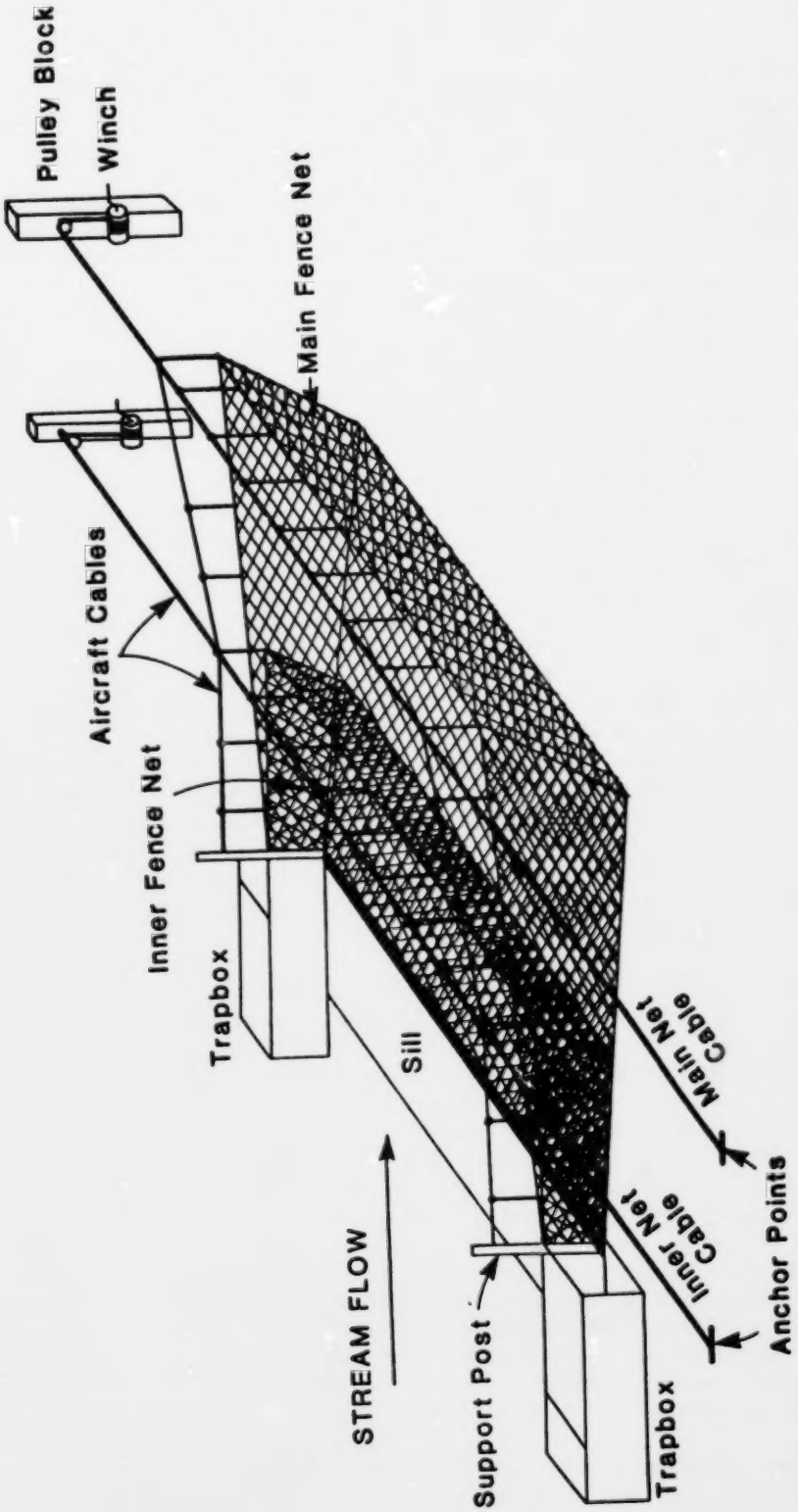

FIGURE 4. The temporary counting fence used at the Keogh River. Note the outer main net barrier and the inner safety net barrier suspended from overhead cables.

An inner net barrier of heavier material was installed to protect the main net from large debris that was not retained by the upstream log boom trash deflector and to serve as an emergency back-up net. It was 22.8 m wide and extended 3 m downstream, with 1.2 m side and front panels. The inner net was made from braided, knotted, 210/160 nylon salmon-seine bunt webbing (Townes Seines Co.) having a 75 mm stretched mesh size. The webbing was hung on 10 mm corkline at a ratio of 1.25 to 1. It was attached to the sill and suspended similarly to the main net.

The overhead cables (7 ply x 19 strand galvanized 8 mm aircraft cable) were strung approximately 4 m above the river bed. The east (high bank) ends of the cables were anchored by wrapping the cable around large alder stumps and securing them with cable clamps. The west (low bank) ends ran through 10 cm yarding blocks to 2500 kg hand winches (Jet Model JW2500) bolted to 15 cm x 15 cm wooden posts. Posts were required as there was no suitable timber on the low bank. Each post was supported and stabilized by 5 guy-wires of 6 mm cable which connected via jaw-to-jaw turnbuckles to 10 mm chain wrapped through deadmen buried 2 m deep in the ground. A deadman located 7 m behind the post provided the main support. Each deadman consisted of a 1.2 m x 0.6 m sheet of 19 mm plywood with a 10 cm x 15 cm timber nailed along the midline, about which the chain was wrapped and secured with a 12 mm shackle.

Prior to mid-October, river flows were low and the entire flow was diverted through the trap boxes by erecting on the sill a 0.6 m high dam of plywood covered with mylar sheeting. Cleaning of the nets was not necessary. To avoid abrasion of the net bottom by boulders which had been placed below the sill to stabilize the substrate, and to maintain a slight upward incline from the sill to the front of the main net barrier at low flow, a cable was strung downstream of the fence at a height of about 1 m and connected to the downstream edge of the net bottom. Raising this cable thus raised the net bottom.

In operation, the downsteam end of the main net barrier was maintained at a height of 1 - 1.5 m above the river surface, using the on-shore winch. The inner net barrier was generally not raised at low flow; at high flows, however, when large debris (e.g., logs) might be in transport, the inner barrier was raised slightly above the water surface to protect the main barrier. Debris such as leaf litter accumulated at the front of the main net, near the waterline. When sufficient debris had accumulated to lower the front noticeably, the fence was cleaned by lowering the support cable to the river bottom to submerge the front of the net. The accumulated debris was washed forward, either off the net or to a point well above the waterline when the fence was raised. Merely lowering and raising the support cable, an operation which took one person only a few minutes, would remove most of the debris. The frequency of cleaning varied with river flow and with the amount of material carried in transport. At freshet during leaf fall, cleaning intervals of 15 - 20 minutes were needed. Under normal conditions, intervals of 8 - 12 hours could be used.

The fence was generally operated continuously (24 h operation); however, during 21-28 October and 3-10 November, the fence was only operated 12-15 h per day in order to provide personnel for other phases of the project.

MARK - RECAPTURE METHODS

Escapements of pink, coho, and chum salmon were estimated using mark-recapture methods. A portion of the fish passing the fence was tagged with 30.5 cm numbered plastic spaghetti tags (Floy Tag and Manufacturing Inc., type FT-4) and estimates derived from tag recoveries in periodic upstream surveys of carcasses by two-person teams walking the river. To ensure that tagging was non-selective by size, sex, and run timing, we planned to randomly mark a fixed proportion of the daily migrants. However, because the run size of pink salmon greatly exceeded expectations and also because large numbers of fish moved past the fence over short periods of time, the proportion of the pink salmon escapement that was marked each day varied; consequently, the recovery data have been stratified in time and the Schaefer modification of the basic Petersen estimator (Ricker 1975) used to estimate pink salmon escapement.

Fish to be marked were dip-netted at random from the trap boxes and anaesthetized in a 2-phenoxyethanol solution (about 0.3 mL per L). Fork length, post orbital-hypural plate length, and adipose fin length (Beacham and Murray 1983) were measured and the fish weighed to the nearest 50 g using a canvas weighing bag and spring balances (Hardy, 5 or 10 kg capacity). Fish sex was determined using external characteristics including head morphology, body shape, and adipose fin size. Fish maturity was determined from the pressure required to extrude sexual products. A fish was categorized as ripe if light pressure along the abdominal cavity extruded eggs or milt; gravid if moderate pressure was required to extrude sexual products, and immature if no sexual products were extruded under moderate presssure. Where possible, scales were taken from coho at a point along the line of join of the posterior end of the dorsal fin and the anterior end of the anal fin several scale rows above the lateral line. Spaghetti tags were attached by forcing a dart bearing the tag through the musculature near the posterior end of the dorsal fin about 1.5 cm below the dorsal surface. Tags were tied with reef knots. Yellow, international orange, and pink tags were used. Late run pink salmon were marked with an opercular punch and the adipose fin was removed. A one-holed paper punch was used to make two holes (5 mm diameter) in the left opercule. A sample of spaghetti-tagged fish was also adipose clipped to assess the frequency of tag loss. To estimate mortality from tagging and handling, samples of 100 spaghetti-tagged and 135 opercular marked pink salmon were held 24 h before being released.

After being marked, fish were released to recover in the pool upstream of the trap box; tagging mortalities were easily recovered and deleted from the tagged population. Prior to the second week of October, most fish that were released above the fence remained in the fence pool because of low water levels upstream. Thus, there was good mixing of tagged and untagged fish and of different run components throughout most of the pink salmon run prior to their moving upriver. Tagging commenced on August 22 and ended on October 18.

All adult salmon in the river were expected to die over the course of the study. Tag recoveries were obtained, therefore, by censusing the population of carcasses for tags. At moderate flows carcasses were visible and relatively easily recovered by hand or by using gaffs. Until the October freshets, the upstream distribution of salmon was confined to the lowermost 2.3 km of river by an apparently impassable log jam, so that most of the popu-

lation could be surveyed. Surveys were conducted by two or three people walking the river. The locations of carcasses and tag recoveries were noted on 1:10,000 maps drawn on waterproof mylar sheets. Carcasses were cut in two with machetes to prevent recounting. Spawning areas were also mapped where they were evident. Tag recovery surveys commenced on September 19 and continued until November 20. Surveys were daily between September 23 and October 14, at two day intervals until October 31 and weekly thereafter. The spatial distribution of survey effort approximated the distribution of live pink salmon which was easily observed under the low flow conditions. Surveys were discontinued when the river froze over in November.

On two occasions, population estimates were derived from the tag ratios obtained in beach seine samples of live pink salmon at the Pumphouse and fence pools.

BENDIX SIDE-SCAN SONAR

The lower 5 km of the Keogh River, and portions of other rivers in the vicinity of Port Hardy, were surveyed in June 1985 to determine the best location to test a Bendix sonar fish counter. The best site in the river was about 20 m upstream of the counting fence under the Bailey bridge (Fig. 3). Reasons for selecting this site were: (1) the water was deep enough for the transducer beam to operate; (2) the stream banks and substrate were relatively stable; (3) there was the possibility of correlating counts indicated by the counter with fish counts past the fence; (4) it would be possible for observers to stand on the bridge and look down on fish passing through the sonar beam; and (5) the proximity to the fence meant that one crew could work on the fence and the sonar simultaneously.

The Bendix 1981 model side scan salmon counter (Bendix Corporation, Sylmar, California) used had three main components: an 18.3 m long aluminum pipe substrate which was laid across the river about 4 m downstream from the Bailey bridge; a transducer which was mounted underwater at the nearshore (west) end of the substrate; and a counting unit and solar panel near the bridge. The substrate had been initially cleaned with enamel reducer, an epoxy primer was then applied and finally it was painted with two coats of imron enamel (Dupont 546 U green). All seams were sealed with pvc tape and silicone glue. A 3.175 cm mesh net was attached to the substrate to prevent fish from swimming under it and galvanized chain (1.25 cm) was attached to the net to weight it down. The substrate was installed between the 23 and 24 July by floating it into position and sinking it as outlined in King (1982). To avoid the remnants of previous bridge foundations the substrate was angled upstream from the west end with the result that the offshore end of the substrate was located under the bridge about two-thirds of the way across the river. To force fish to swim through the transducer beam, fences of 5 cm 10 gauge galvanized Weldmesh (Industrial Wire & Iron Works) were installed between the stream banks and the substrate ends. The fences were held in place by metal bars, driven into the river bottom, which were secured to the Bailey bridge. To prevent fish from passing beneath these fences, flexible vinyl chainlink fencing was attached near the bottom of the fences and sand bags were then placed along its length.

The transducer unit was installed on September 25. It was aimed using the metal target attached to the offshore end following the manufacturer's instructions (Bendix Corp. 1984). A Tectronix Model D13 dual beam ocilloscope was used to monitor the reflections. Beam alignment was confirmed by placing targets at known positions along the substrate and noting their appearance on the oscilloscope trace. It was not possible to calibrate the counter against visual fish counts because of humic staining of the river water. Instead the count was calibrated daily by comparing 1 h machine counts against counts of "fish" traces on the oscilloscope. This method is subjective because it requires that the observer distinguish fish traces from others on the basis of peak height and duration. The characteristics of fish traces were ascertained by examining oscilloscope traces during the low water period when large numbers of pink salmon were milling over the substrate. The hourly machine counts in the 16 sectors into which the substrate is divided were adjusted to fish counts following the procedure outlined in King (1982); hourly sector counts which the machine identifies as debris are replaced by the average value for fish counts and the resulting values are scaled by the calibration factor to yield "true" fish counts.

RESULTS

Data collected during the study are published in a separate report (Johnston et al. 1986).

TEMPERATURE AND STREAM FLOW MEASUREMENTS

Mean daily water temperatures (Fig. 5) decreased from about 18.4°C in mid-August to 0°C when the river froze over in late November. Water temperature remained above 10 °C until mid-October. Daily mean stream flow (Fig. 6) varied almost 500-fold between July 26 and December 12, from a minimum of about 0.07 $m^3.s^{-1}$ (2.6 cfs) to a maximum of 33.8 $m^3.s^{-1}$ (1190 cfs), with instantaneous rates as high as 35.9 $m^3.s^{-1}$. Discharge in the Keogh River broadly reflected patterns of rainfall. The extremely low streamflows measured throughout August and September were associated with below average precipitation (11.8 mm and 53.5 mm respectively, 17 and 39% of normal, Atmospheric Environment Service 1985). A release of stored water from Keogh Lake on October 2 produced little increase in streamflow 4 or 5 days later. The large and irregular increases in streamflow in mid-October were associated with above average autumn rainfall (307.8 mm in October, 26% above normal, Atmospheric Environment Service 1985). Cold weather throughout November froze the river and caused precipitation to acumulate as snow which produced a major flood in early December when heavy rains washed the accumulation into the river.

FENCE OPERATIONS

Fence operations were interrupted three times during the high flow period by failures of hardware components in the net support system. Consequently, the temporary fence was not fishing for 6 of 83 days (7% of total time) as the

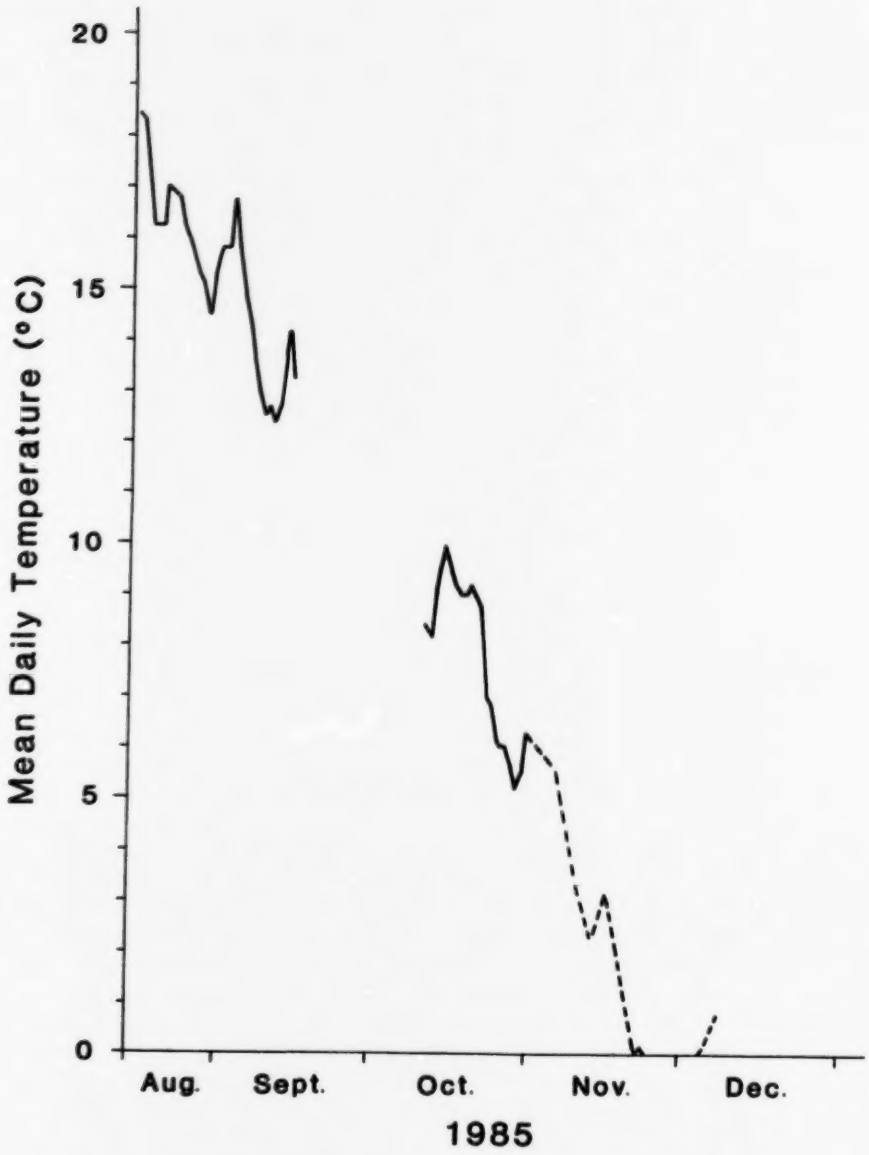

FIGURE 5. Daily mean water temperatures measured at the Keogh River fish counting fence from August to December 1985. Solid lines represent continuous temperature records while dotted lines represent periodic temperature measurements.

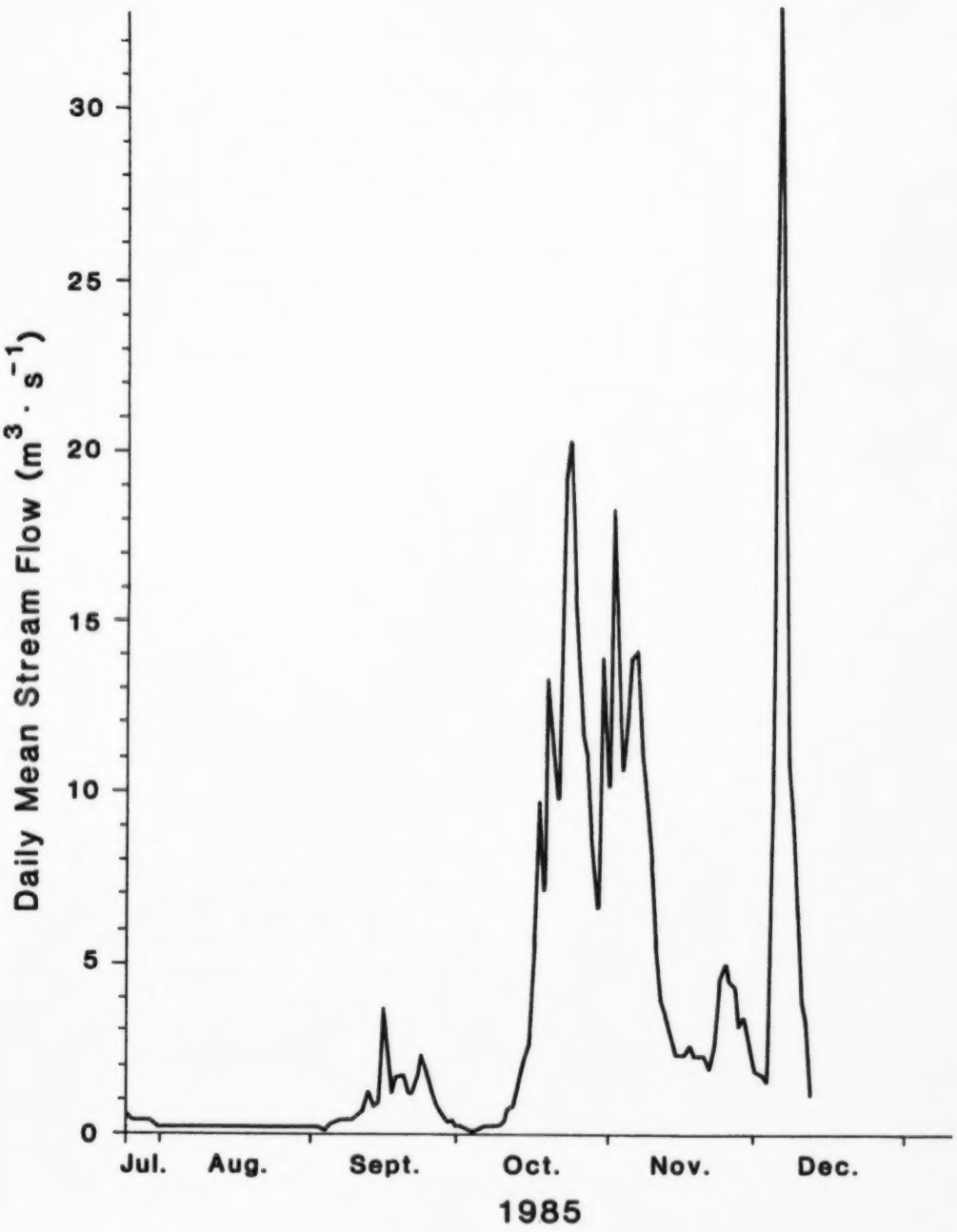

FIGURE 6. Daily mean stream flow measured at the old pumphouse site, about 1.3 km upstream of the Keogh River fish counting fence.

result of unplanned interruptions. A decision not to operate the fence at night during a period when personnel were required for daily tag recovery surveys reduced the fishing time by a further 7.5 days (9%).

The longest interruption (4 days) occurred on October 17 from the failure of a chain in the guy-wire system which supported the winch post on the main net. Although repairs merely involved replacing the chain by one of a heavier gauge, they were delayed by the need for a backhoe to access the chain. It should be noted that the guy-wire system would not be required at many sites where large timber could be used to support winches and anchor cables. A break in the main net cable caused an 8 h interruption on 30 October; the cable was repaired by splicing in a new piece. The rupture of the chain link attaching the pulley block to the winch post produced a 16 h interruption on 1 November; repairs were made by replacing the piece. These latter two failures were probably a consequence of the first, which led to an over stressing of components.

The first and second interruptions resulted from the accumulation of leaf litter on the net during high flow periods when the fence net was not continuously tended. The fence was successfully operated through periods of considerably higher flows by having personnel present to clean the net whenever required. The design did, in fact, allow the rapid and efficient cleaning of the fence by onshore personnel at no risk to themselves even under high flows. Debris did accumulate in pockets where the side panels joined the front of the main net barrier; however, such accumulations did not affect the operation of the fence. Cleaning frequency varied considerably with flows and the amount of debris in transport (Fig. 7). At high flows (about 21.7 $m^3.s^{-1}$) during heavy leaf-fall periods, cleaning intervals as short as 20 min were required. At low flows during periods when little or no debris was carried, however, the interval between cleanings could be days.

During high flow periods, the area from the sill to the downstream wing dam was a violent rapid. As the fence was in the middle of the rapid, stresses on the fence were high. Moreover, the location of the temporary fence resulted in abrasion of the net barriers on large boulders below the sill. Because of the heavy material from which it was constructed, abrasion was not a serious problem for the innermost net barrier. The main net barrier, which was of lighter material, was more subject to abrasion. When low flows permitted access to the net, we were able to mend holes in the fence. Holes were always quickly mended, the inner net barrier was present, and high flows forced fish to the sides of the channel away from the areas where abrasion occurred. Data presented below indicate that holes had little real effect on the fence's ability to act as a barrier to upstream fish movement.

SALMON ESCAPEMENTS

Although large numbers of pink salmon were observed in the small embayment off the mouth of the Keogh River from early August, low river flows and high water temperatures probably restricted their access to the river. Pinks did not enter the river until mid-August and congregated in the two lowermost pools, about 100 m below the counting fence. Under the low flow conditions, pink salmon entered the river and moved upstream on high tides and retreated

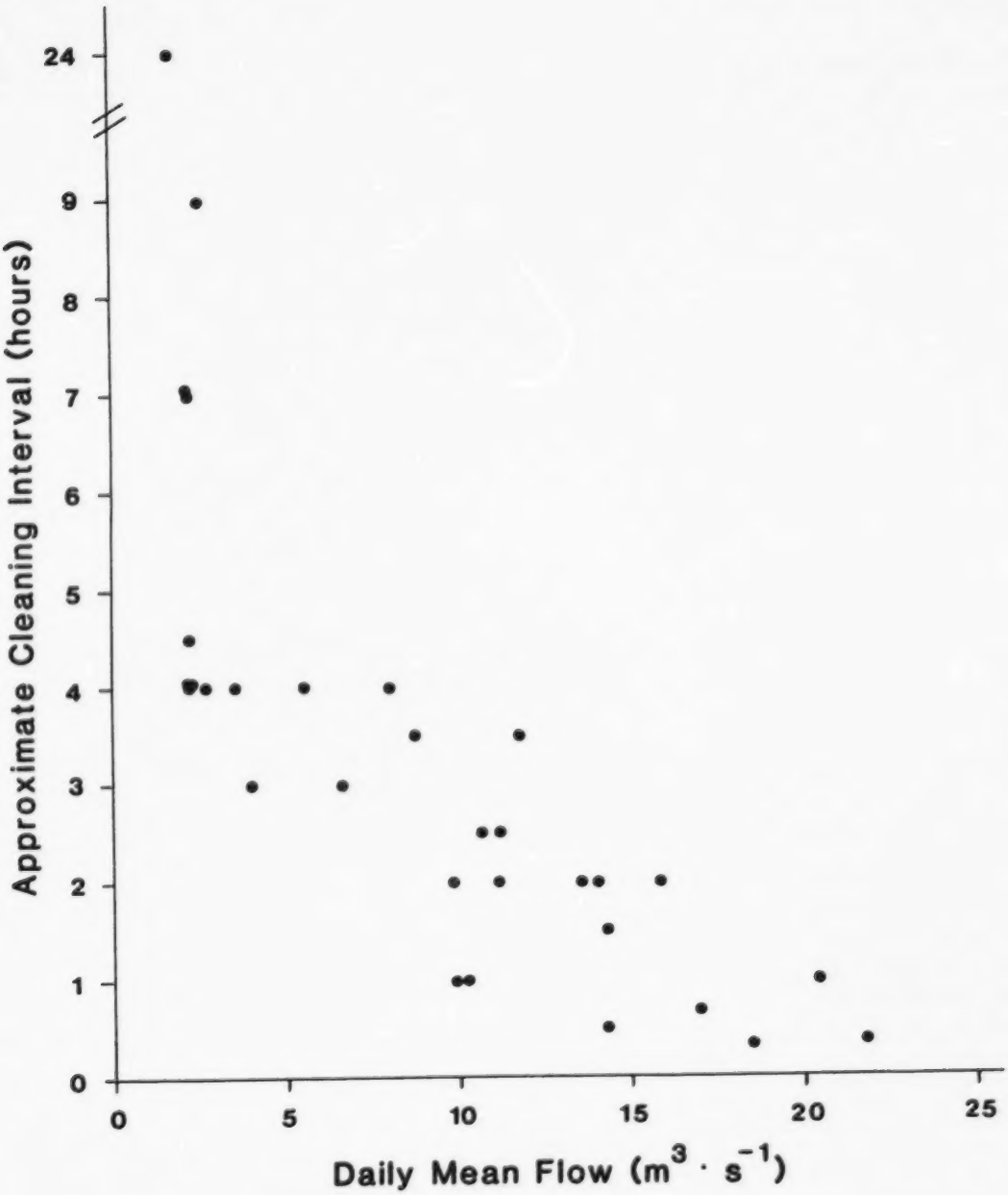

FIGURE 7. The dependence of the interval between cleaning the temporary fish counting fence on river discharge.

with the ebbing waters. Pink salmon appeared at the fence in very low numbers in late August (Fig. 8), but significant numbers did not appear until mid-September when rains increased river discharge (Fig. 6).

The main portion of the pink salmon run into the Keogh River occurred between mid-September and mid-October (Fig. 8). In total, 33,921 pink salmon were caught at the counting fence (Table 1). Of these, 1,295 were used as brood stock by the Northern Vancouver Island Salmonid Enhancement Association and 17 were killed during handling and tagging. The spawning escapement was therefore 32,609 fish. Because low flows restricted fish passage to a narrow and shallow channel in the extensive riffle area between the fence and the next pool downstream, migrating pink salmon were heavily preyed upon by black bears and bald eagles. We estimate predation losses to average about 25-30 fish per day throughout the main migration period, with a maximum daily loss of about 200-250 fish on one occasion. Throughout the early part of the run, when fish moved into and out of the river, a small number of moribund fish were found downstream of the trap; these fish may have been diseased as internal and external tissue inflammation was seen. On September 22, there was a kill of 500+ pink salmon in the last holding pool before the fence. Known mortality to the pink salmon run was at least 1250-1400 fish before the fence count. Thus, the total pink salmon run into the Keogh River was about 36,000 fish.

TABLE 1. Total numbers of upstream migrating fish caught at the Keogh River counting fence between 26 July and 5 December, 1985.

Species	Total Catch	Mortalities	Brood stock Removal	Escapement	Tagged Fish Released
Pink salmon	33,921	17	1,295	32,609	3,214
Coho salmon	993	2		991	148
Chum salmon	196			196	32
Steelhead trout (adults)	1			1	
Cutthroat trout	9			9	
Dolly Varden char	665			665	

Daily catches of pink salmon at the fence fluctuated irregularly (Fig. 8) but at least three major waves of migrants were distinguishable, occurring in mid-September, early October, and mid-October. Although an increase in river flow appeared to initiate the upstream migration, there was no relationship between daily mean flows and daily catches ($r=0.076$, $n=49$; ns).

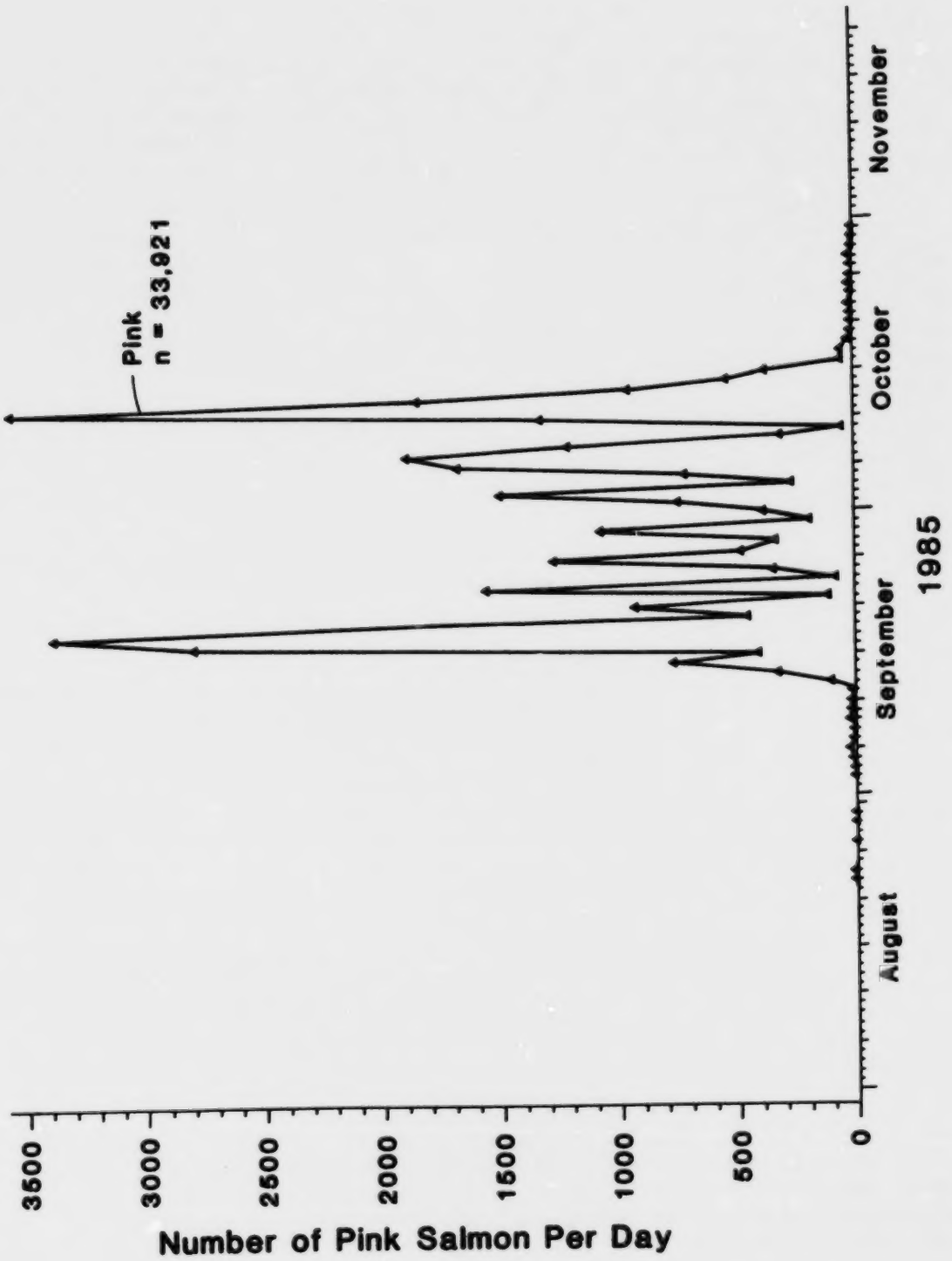

FIGURE 8. The daily catch of pink salmon at the Keogh River counting fence between 26 July and 5 December 1985.

The size of the pink salmon run was also estimated by integrating the area-under-the-catch curve (Waldichuk 1984a), assuming that the fence had been operated at 3 day and 7 day intervals. Both sampling procedures gave similar ranges of estimates, between 23,661 and 40,560 for all possible combinations of 3 day sampling and between 19,096 and 41,118 for 7 day sampling. Variability in the estimates was also similar for the two sampling intervals (unbiased coefficients of variation of 23.5% and 20.0% for 3 and 7 day intervals, respectively).

Biological characteristics of the pink salmon run were obtained from a subsample of 3,232 fish, most of which were tagged. Size characteristics are summarized by sex in Table 2. The post orbital-hypural plate length was the measure of body length used in all analyses since it is less affected than fork length by changes in body morphology associated with sexual maturity. Females were slightly longer on average than males ($t=7.03$, $p<0.05$). As males and females differed significantly in their body size - weight relationships (analysis of covariance, $p<0.05$), separate predictive regressions of body weight on body size were computed (Table 2). Because the slopes of the regressions differ, comparisons of weights will vary with body size, but females are slightly heavier (1342 g versus 1325 g) than males at the population mean body size. The sex ratio was 1.53 males per female.

Estimates of the duration of stream life and the extent of upstream migration for pink salmon were obtained from tagged carcass recoveries. The average interval between the date of tagging and the date of tag recovery (Table 2) did not differ (t-test, $p>0.05$) between sexes and averaged 16 days although intervals as long as 60 days were observed. The locations of tag recoveries by 100 m river sections (Fig. 9) suggest that several reaches of the lower river were heavily utilized, but especially a riffle-pool sequence formed by a large log jam at 0.9 km and a stretch of river between two large jams at 2.1 and 2.3 km. Because of low flow conditions, the log jam at 2.3 km was a barrier to upstream migration until October 8. Few fish were ever observed beyond it. Some carcasses were, however, found considerably farther upriver although the majority of pink salmon were seen less than 3 km from the fence. Visual observations of redds confirmed that the area in the vicinity of the 0.9 km log jam was an important spawning area for pink salmon. Redds were also seen in the shallow riffle area 0.2 km above the fence, below the airport boundary treeline at 0.5 km, and in a large side channel at about 1.2 km. Areas such as between the Rupert Main and Highway bridges and below the West Main bridge, which had been important spawning areas in other years, were not utilized greatly. However, visual observations of redds were difficult to make under the higher flow conditions which prevailed when pink salmon reached the upriver areas.

The timing of the coho salmon run was bimodal (Fig. 10). A portion of the run entered the river in mid-September but most of the coho entered during a few days in mid-October. A total of 993 coho were caught at the fence, of which two died during tagging to give known escapement of 991 fish. The escapement figure is low since the fence was not fishing during the latter part of the coho run; however, visual counts of coho passing over the sill were made during the day during this time. Coho in the Keogh River have been reported as migrating during storm flows (B. Ward, Fisheries Research Section, MOE, pers. comm.). However, daily catches were not correlated with daily mean flows ($r=0.185$, $n=28$; ns) although increased catches were generally obtained

TABLE 2. Size, weight, stream life, and recovery location data for salmonids in the Keogh River, fall 1985.

PINK SALMON: MALES

Parameter	N	Minimum	Maximum	Mean	SD
Fork length (mm)	1,949	398	615	498.3	32.4
Post orbital-hypural length (mm)	1,949	300	525	412.7	26.9
Wet weight (g)	1,949	500	2,400	1,324.3	261.7
Stream life (d)	362	1	60	16.7	9.1
Recovery location (100 m)	357	1	48	10.5	7.8

log (weight) = -4.350 + 2.768 log (post orbital length)

PINK SALMON: FEMALES

Parameter	N	Minimum	Maximum	Mean	SD
Fork length (mm)	1,273	398	572	491.2	20.4
Post orbital-hypural length (mm)	1,273	330	500	418.8	18.6
Wet weight (g)	1,272	550	2,300	1,376.9	175.2
Stream life (d)	254	1	52	15.6	9.4
Recovery location (100 m)	253	1	53	12.4	7.5

log (weight) = -3.773 + 2.567 log (post orbital length)

TABLE 2 (Continued)

COHO SALMON: MALES

Parameter	N	Minimum	Maximum	Mean	SD
Fork length (mm)	112	245	800	511.8	172.9
Post orbital-hypural length (mm)	112	170	665	422.0	140.0
Wet weight (g)	111	100	7,400	2,274.8	1,962.8
Stream life (d)[a)]					

COHO SALMON: FEMALES

Parameter	N	Minimum	Maximum	Mean	SD
Fork length (mm)	16	358	739	650.3	92.2
Post orbital-hypural length (mm)	16	300	635	541.3	87.2
Wet weight (g)	16	500	5,700	3,721.9	1,389.7
Stream life (d)[a)]	3	4	11	6.7	3.8

a) two coho of unknown sex had stream lives of 1 and 36 d

log (weight) = -4.584 + 2.973 log (post orbital length)

TABLE 2 (Continued)

CHUM SALMON: MALES

Parameter	N	Minimum	Maximum	Mean	SD
Fork length (mm)	13	579	778	684.4	52.0
Post orbital-hypural length (mm)	13	485	625	569.3	34.9
Wet weight (g)	13	2,275	5,400	3,569.2	931.2
Stream life (d)	1	9	9	9	

CHUM SALMON: FEMALES

Parameter	N	Minimum	Maximum	Mean	SD
Fork length (mm)	20	610	732	670.6	38.6
Post orbital-hypural length (mm)	20	510	622	569.4	36.7
Wet weight (g)	20	2,300	5,175	3,796.3	766.6
Stream life (d)	4	16	33	22	8.0

log (weight) = -4.529 + 2.936 log (post orbital length)

DOLLY VARDEN: MALE + FEMALE

Parameter	N	Minimum	Maximum	Mean	SD
Fork length (mm)	126	148	405	236.9	54.6
Post orbital-hypural length (mm)	126	125	345	204.1	44.9
Wet weight (g)	126	25	750	169.0	125.6

log (weight) = -4.415 + 2.848 log (post orbital length)

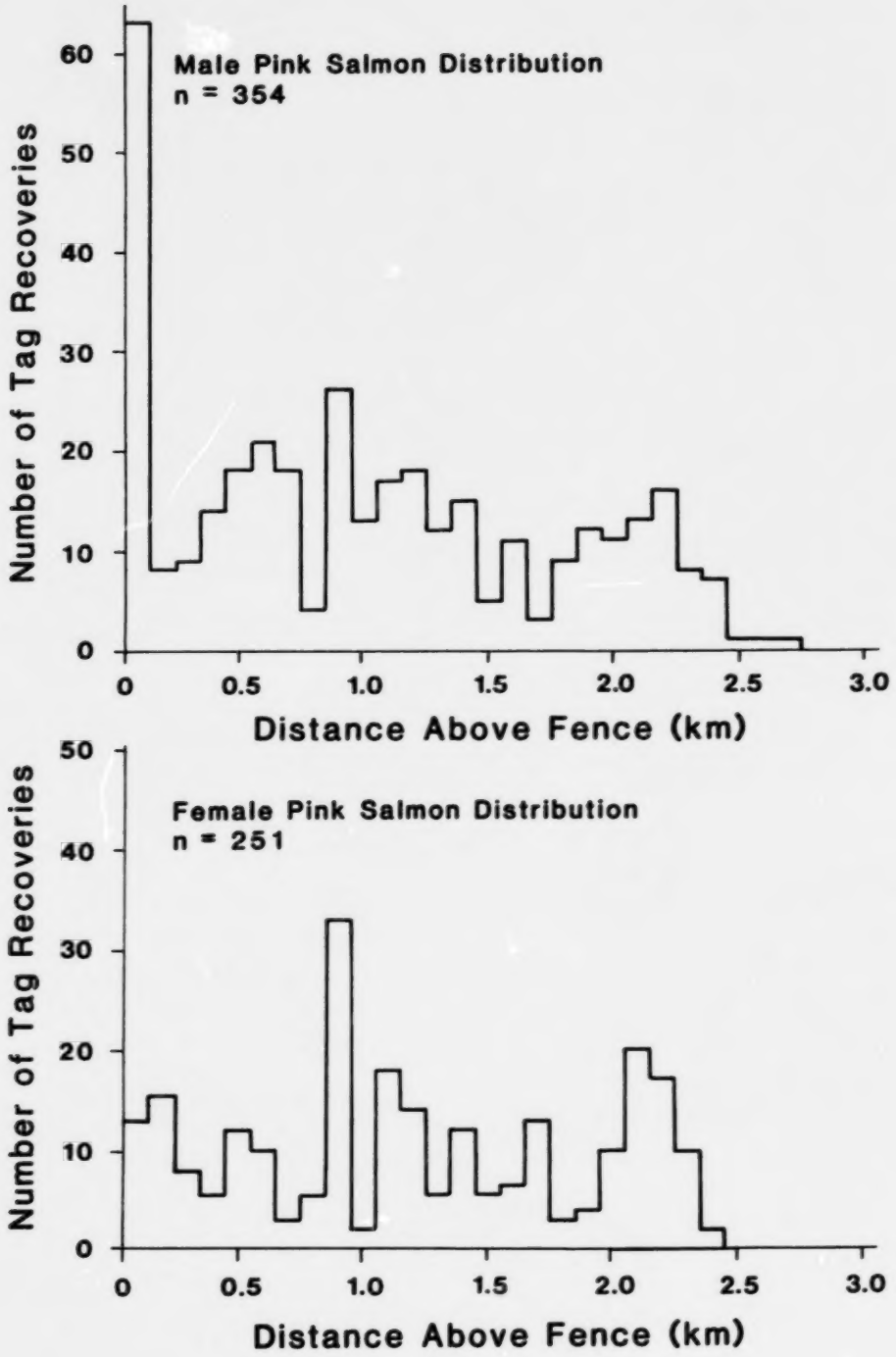

FIGURE 9. The distribution of tagged pink salmon carcasses by 100 m river sections above the Keogh River counting fence.

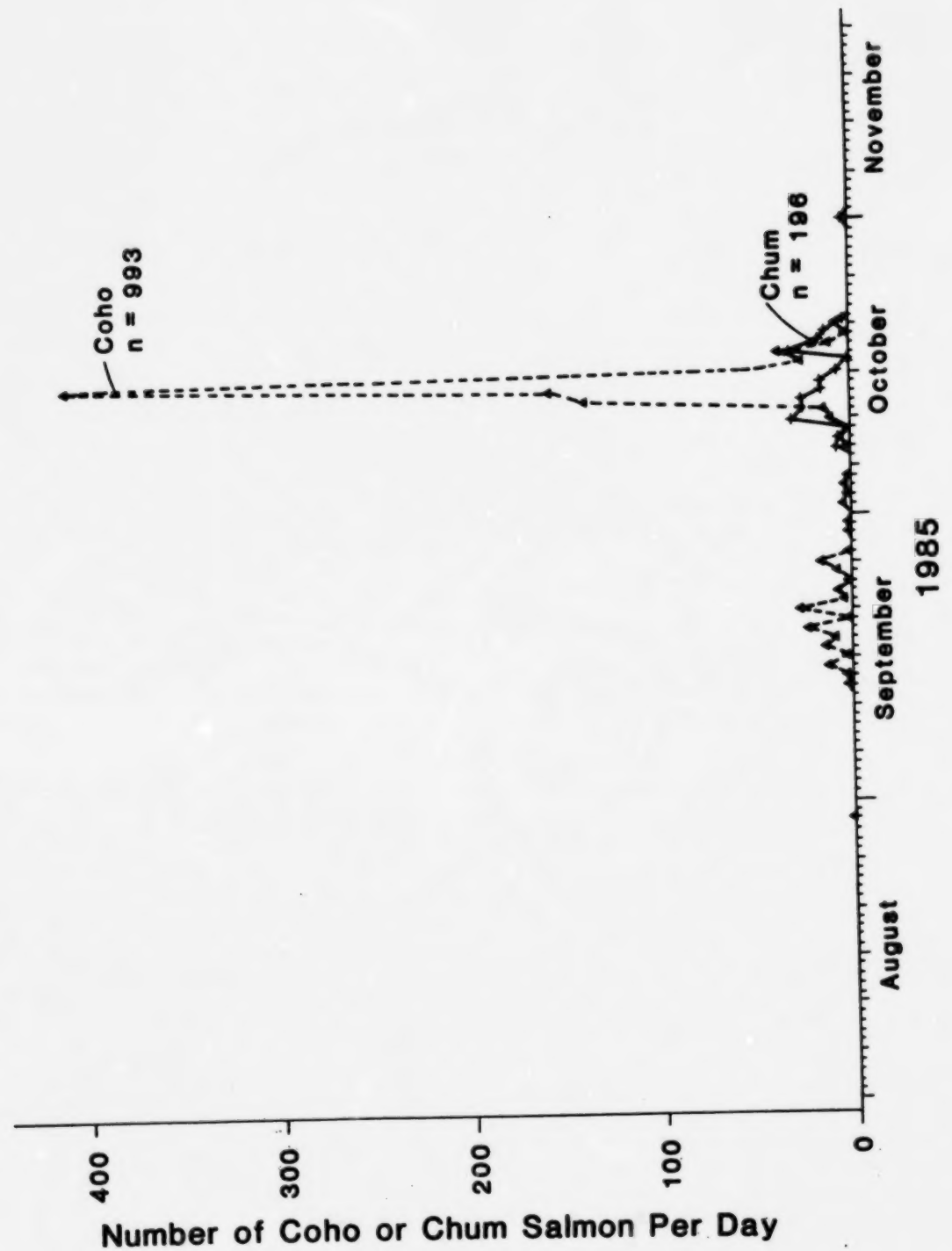

FIGURE 10. The daily catches of coho and chum salmon at the Keogh River counting fence between 26 July and 5 December 1985.

at flows of 1-2 $m^3.s^{-1}$. The area-under-the-catch curve method gave rather worse estimates of escapement for coho than for pinks. Estimates using a 3 day interval ranged from 705 to 1563 for all possible combinations, with a CV of 43.9%. Estimates using a 7 day interval ranged from 371 to 2975, with a CV of 90.7%. The much worse performance of the 7 day interval sampling in this case probably results from the short duration of the major portion of the run, which biased the estimate up or down depending on whether the sampling detected the peak.

Biological characteristics of the coho salmon run were obtained from a sample of 221 fish (Table 2). The weight distribution of male coho was bimodal, with one mode between 300-400 g and a second mode at about 4000 g; the smaller fish were jacks. The incidence of jacks cannot be accurately estimated since they were not always kept separate in the data, but the ratio of jacks to large fish was 1.8:1 in a sample of 76 fish from the end of the run. The size-weight relationship was the same for male and female coho (ancova, $p>0.05$) (Table 2). The sex ratio was not determined because of the large proportion of fish which could not be sexed from external characteristics.

Only 21 coho carcasses were recovered from the mainstem Keogh River. Seven of these were found upstream of the West 80 logging bridge in the headwaters of the river while eight were found within 0.5 km of the fence. Redds were seen only in the headwater area near the outlets of Keogh and O'Connor Lakes, upstream of the W104 bridge, and between Muir Lake and the West Main bridge. No coho carcasses or redds were seen in either Misty Lake outlet stream, Long Lake outlet stream or in West Tributary Creek, but several live adult fish were seen in the latter. The average stream life of the five tagged carcasses recovered was about 13 days, with a maximum of 36 days (Table 2).

Chum salmon first appeared at the fence on October 7 and were present into November (Fig. 10). Most of the run passed upstream in two pulses near the middle of October. A total of 196 chum were counted through the fence, but 68 of these were visual counts at times when the fence was not operating. The run is probably underestimated as a consequence. Daily catches of chum salmon were not correlated with flows ($r=-0.066$, $n=13$; ns). The area-under-the-catch curve method gave estimates ranging from 147 to 237 for 3 day sampling intervals and between 21 and 434 for 7 day sampling intervals. The coefficient of variation of the 3 day interval estimates was 20.6% while that of the 7 day estimates was 71%.

Biological characteristics of a subsample of the chum run are given in Table 2. The size-weight relations were identical for males and females (ancova; $p>0.05$); the combined regression is given in Table 2. The sex ratio was 0.65 males per female. Chum salmon spawned in the lower reaches of the river and in very small tributaries. Redds were seen in the old river channel about 100 m upstream of the fence, in the airport drainage ditch about 150 m upstream of the fence, and near the log jam at 0.9 km where chum salmon appeared to use the same areas as the pink salmon which had preceded them. Of the 102 carcasses recovered, 85% were found within 1.5 km of the fence and none was found more than 5.2 km upstream. The average stream life of the 5 tag recoveries was 19 days; the range was 9 to 33 days.

Dolly Varden char were caught from the third week of August until the end of October, but brief pulses between 15-17 September and 12-15 October accounted for 20% and 47%, respectively, of the 685 fish taken. Two and possibly three weight classes occurred with modal weights about 160 g, 320 g, and 500 g. Size characteristics are summarized in Table 2. Catches of other species are summarized in Table 1.

MARK - RECAPTURE ESTIMATES

A total of 6,459 pink salmon carcasses were examined during stream surveys. Of these, 620 were tagged with numbered spaghetti tags, 52 were marked with an opercular punch hole, and 37 had prominent tag holes on the back but did not have a tag. Tag recoveries have been stratified by time of tagging and time of recovery and the population size estimated using the Schaefer method (Ricker 1975). The Schaefer method is more appropriate than the simple Petersen estimate (Ricker 1975) because tagging was selective by time (i.e., non-proportional to daily catches) and because the ratio of recoveries to number tagged varied with time of tagging. Fish which are marked with an opercular punch or which bear only tag scars cannot be identified by their time of marking. Such fish have been allocated in the same proportion as recoveries of known tagging date in the case of tag hole fish and in proportion to the time of marking for opercular punched fish (Table 3). The total estimate of 30,289 is about 7% below the known escapement of 32,609 pink salmon.

Because the asymptotic variance of the Schaefer estimator has never been calculated (Seber 1982), confidence limits on the population estimate were determined through a Monte Carlo technique in which the estimate was repeatedly recalculated (n=1,000) drawing the tag recovery data from Poisson distributions which had the observed values as their means. The procedure is similar to that suggested by Ricker (1975) to obtain approximate confidence limits for the Petersen estimator. Approximate 95% confidence limits were then obtained directly from the calculated distribution of population estimates, and are 25,685 to 31,042 which do not encompass the known escapement value.

Simpson (1984) argued that recoveries of carcasses at the counting fence should be excluded from comparisons of mark-recapture estimates to fence counts since the dead-on-the-fence usually have an unusually high proportion of tags and would not be available under the usual conditions in which a mark-recapture estimate would be used. If the fence recoveries are excluded, the Schaefer estimate (Table 4) becomes 32,154 which is within 1.4% of the known escapement. The 95% confidence limits for the estimate are 26,626 to 32,220 and do not include the known value.

For comparison, the simple Petersen estimates have been calculated. The Petersen estimate is 29,252 (95% limits of 27,181 - 31,482) using all the tag recovery data and 30,161 (95% limits of 27,908 - 32,640) omitting the fence recoveries. Both the Petersen estimates are below the known value. Petersen estimates and their 95% confidence limits are given in Table 5 for all saimon species. The 95% limits for coho include the known escapement while those for chum are greater than the known escapement. The agreement between the fence counts and the mark-recapture estimates for pink and coho salmon suggest that

Table 3. Schaefer mark-recapture estimate of the pink salmon escapement, using tag recoveries from carcasses.

SCHAEFER MARK-RECAPTURE POPULATION ESTIMATE
(tag hole carcasses allocated proportionately to tagged fish count)

WEEK OF RECOVERY (j)		WEEK OF TAGGING (i) i=1 24-Aug	i=2 31-Aug	i=3 07-Sep	i=4 14-Sep	i=5 21-Sep	i=6 28-Sep	i=7 05-Oct	i=8 12-Oct	TAGGED FISH RECOVERED Rj	TOTAL FISH RECOVERED Cj	Cj / Rj
j=1	21-Sep				4					4	26	6.500
j=2	28-Sep				22	14	15			51	291	5.706
j=3	05-Oct	1			14	42	56	16		129	916	7.101
j=4	12-Oct	1			12	53	135	76	7	284	2354	8.289
j=5	19-Oct			1	5	31	57	57	26	177	1731	9.780
j=6	26-Oct					7	7	8	6	28	552	19.714
j=7	02-Nov					5	10	2	3	20	346	17.300
j=8	09-Nov					1	3	1	2	7	116	16.571
j=9	16-Nov					1	3	3		7	83	11.857
j=10	23-Nov							2		2	44	22.000
TAG RECOVERIES (Ri)		2	0	1	57	154	286	165	44	709	6459	9.110
TOTAL FISH TAGGED (Mi)		8	3	16	289	719	906	662	611			
Mi / Ri		4.00		16.00	5.07	4.67	3.17	4.01	13.89			

WEEK OF RECOVERY (j)		WEEK OF TAGGING (i) i=1 24-Aug	i=2 31-Aug	i=3 07-Sep	i=4 14-Sep	i=5 21-Sep	i=6 28-Sep	i=7 05-Oct	i=8 12-Oct	TOTAL		
j=1	21-Sep	0	0	0	132	0	0	0	0	132		
j=2	28-Sep	0	0	0	636	373	271	0	0	1281		
j=3	05-Oct	28	0	0	504	1392	1260	456	0	3640		
j=4	12-Oct	33	0	0	504	2051	3545	2527	806	9466		
j=5	19-Oct	0	0	156	248	1415	1766	2237	3531	9353		
j=6	26-Oct	0	0	0	0	644	437	633	1643	3357		
j=7	02-Nov	0	0	0	0	404	548	139	721	1811		
j=8	09-Nov	0	0	0	0	77	157	66	460	762		
j=9	16-Nov	0	0	0	0	55	113	143	0	311		
j=10	23-Nov	0	0	0	0	0	0	177	0	177		
TOTAL		62	0	156	2025	6413	8097	6377	7160	30289	24-Oct	TOTAL
ACTUAL		8	3	61	1258	9730	4785	5181	9535	30561	2048	32609

Table 4. Schaefer mark-recapture estimate of the pink salmon escapement, omitting fence-caught carcass data.

SCHAEFER MARK-RECAPTURE POPULATION ESTIMATE
(fence recoveries omitted)
(tag hole carcasses allocated proportionately to tagged fish count)

	WEEK OF RECOVERY (j)	WEEK OF TAGGING (i) i=1 24-Aug	i=2 31-Aug	i=3 07-Sep	i=4 14-Sep	i=5 21-Sep	i=6 28-Sep	i=7 05-Oct	i=8 12-Oct	TAGGED FISH RECOVERED Rj	TOTAL FISH RECOVERED Cj	Cj / Rj
j=1	21-Sep				4					4	26	6.500
j=2	28-Sep				22	14	15			51	291	5.706
j=3	05-Oct	1			14	42	56	16		129	916	7.101
j=4	12-Oct	1			12	53	135	76	7	284	2354	8.289
j=5	19-Oct			1	3	18	37	28	12	99	1200	12.121
j=6	26-Oct					7	7	8	6	28	552	19.714
j=7	02-Nov					5	10	2	3	20	346	17.300
j=8	09-Nov					1	3	1	2	7	116	16.571
j=9	16-Nov					1	3	3		7	83	11.857
j=10	23-Nov							2		2	44	22.000
TAG RECOVERIES (Ri)		2	0	1	55	141	266	136	30	631	5928	9.395
TOTAL FISH TAGGED (Mi)		8	3	16	289	719	906	662	611			
Mi / Ri		4.00		16.00	5.25	5.10	3.41	4.87	20.37			

	WEEK OF RECOVERY (j)	WEEK OF TAGGING (i) i=1 24-Aug	i=2 31-Aug	i=3 07-Sep	i=4 14-Sep	i=5 21-Sep	i=6 28-Sep	i=7 05-Oct	i=8 12-Oct	TOTAL		
j=1	21-Sep	0	0	0	137	0	0	0	0	137		
j=2	28-Sep	0	0	0	660	407	292	0	0	1358		
j=3	05-Oct	28	0	0	522	1521	1354	553	0	3979		
j=4	12-Oct	33	0	0	523	2240	3811	3066	1182	10855		
j=5	19-Oct	0	0	194	191	1113	1528	1652	2962	7640		
j=6	26-Oct	0	0	0	0	704	470	768	2409	4351		
j=7	02-Nov	0	0	0	0	441	589	168	1057	2255		
j=8	09-Nov	0	0	0	0	85	169	81	675	1010		
j=9	16-Nov	0	0	0	0	60	121	173	0	355		
j=10	23-Nov	0	0	0	0	0	0	214	0	214		
TOTAL		62	0	194	2032	6571	8334	6676	8285	32154	24-Oct	TOTAL
ACTUAL		8	3	61	1258	9730	4785	5181	9535	30561	2048	32609

most of the runs were enumerated. However, the data indicate that a portion of the chum run was not counted at the fence.

TABLE 5. Petersen estimates of salmon escapements in the Keogh River based on recoveries of tagged carcasses and on tag ratios in beach seine hauls.

Species	Known Escapement	Number Marked	Number Censused	Tag Recoveries	$\hat{N}$	95% limits
Pink salmon	32,609	3,214	6,459	709	29,252	27,181-31,482
Pink salmon[a)]	32,609	3,214	5,928	631	30,161	27,908-32,640
Coho salmon	991	148	21	5	546	258- 1,260
Chum salmon	196	32	102	5	566	267- 1,307
Pink salmon[b)]	16,413	2,032	613	99	12,483	10,357-15,350
Pink salmon[b)]	17,022	2,158	118	19	12,846	8,679-22,341

a) calculation omits carcasses recovered at the fence
b) data from beach seine hauls of live fish

Population size estimates for pink salmon were also made using tag ratio data obtained from beach seine hauls on two occasions. The resulting estimates (Table 5) were about 25% lower than the known escapements and had broad confidence intervals. Nevertheless, the beach seine data were quickly and easily obtained and gave reasonable accuracy.

A problem with surveying carcasses for marked fish is that the stream surveys could only be done at flows less than about 10 $m^3.s^{-1}$. Between mid September and mid December, flows exceeded this value 25% of the time. Thus, the ability to obtain tag ratios by censusing carcasses may be severely restricted.

During the stream surveys, a large number (358) of loose spaghetti tags were found. This was not wholly unexpected since the decay of carcasses would release some tags. Loose tags thus indicated "mortality" in the population of carcasses which also occurred undetected for unmarked fish. However, the finding of carcasses bearing tag holes indicated that some tag loss took place, with the loss affecting about 5.2% (37 of 709) of the tagged fish. No additional adjustments for tag loss have been applied to the above population estimates. No tag loss occurred when tagged fish were held at the fence, but erosion of the tag holes was seen in spent fish (Fig. 11).

FIGURE 11. The carcass of a spent pink salmon, showing the erosion of the flesh around the spaghetti tag. Note that the tag is only attached by a thin dorsal strip of flesh.

BENDIX SIDE-SCAN SONAR ESTIMATES

The estimates of the numbers of fish passing upstream which were derived from the sonar counts (Fig. 12) were typically several orders of magnitude greater than the daily fence counts of escapements. Machine counts were calibrated against oscilloscope counts, and the data were adjusted to remove debris counts. Beam alignment was checked to ensure that the high machine counts did not result from transducer misalignment. It is likely that the sonar was detecting turbulence. Counts in some sectors in which turbulent flow was visually evident were significantly correlated with average daily flows (Fig. 13). Visual observations suggest that the amount of turbulence increased at higher flows. In this instance, the turbulence resulted in part from flow around the bridge foundations upstream of the sonar substrate. However, turbulence may be a general problem in relatively shallow rivers like the Keogh. The inability to find suitable sites may severely restrict the use of the Bendix unit in coastal rivers.

Although the sonar unit provided inaccurate escapement estimates, it was extremely reliable when it could be used and performed without malfunction over conditions which included floods and freezing. However, because of its location it could be used only 70% of the time after the installation of the transducer. The accumulation of debris on the substrate and its skirting was not a serious problem as branches, etc. were easily removed by hand at lower water levels.

DISCUSSION

The three methods used to enumerate spawning salmonids in the Keogh River differed greatly in cost, reliability, accuracy, and precision (Table 6). The results emphasize the tradeoffs involved in the selection of an enumeration technique.

The comparison in Table 6 suggests that the Bendix side-scan sonar is unsuitable for use in small, shallow, variable flow coastal rivers like the Keogh. The sonar was the most expensive, least reliable in terms of the proportion of time that it could be used during the coho migration, and the least accurate of the three methods. These disadvantages are not offset by its greatly reduced operating costs. The poor accuracy and reliability result from the difficulty in finding a suitable site for the apparatus in a shallow, variable flow river. Areas of the Keogh River with sufficient water depth to operate the transducer and with a sufficiently level bottom to deploy the sonar substrate were the large pools in which salmon congregate. When salmon mill about the pools at low flows rather than migrating directly upstream, the multiple passages of fish through the beam path produce machine counts with little correspondence to escapements. The problem is compounded by the subjectivity in calibrating the sonar unit from the oscilloscope, as is necessary when fish cannot be counted visually in the dark humic-stained river water. A more serious problem was the spurious counts which resulted from the turbulent flow over the substrate. In shallow rivers that are subject to freshets, strong eddies are evident in both riffle and pool areas. Therefore, it would

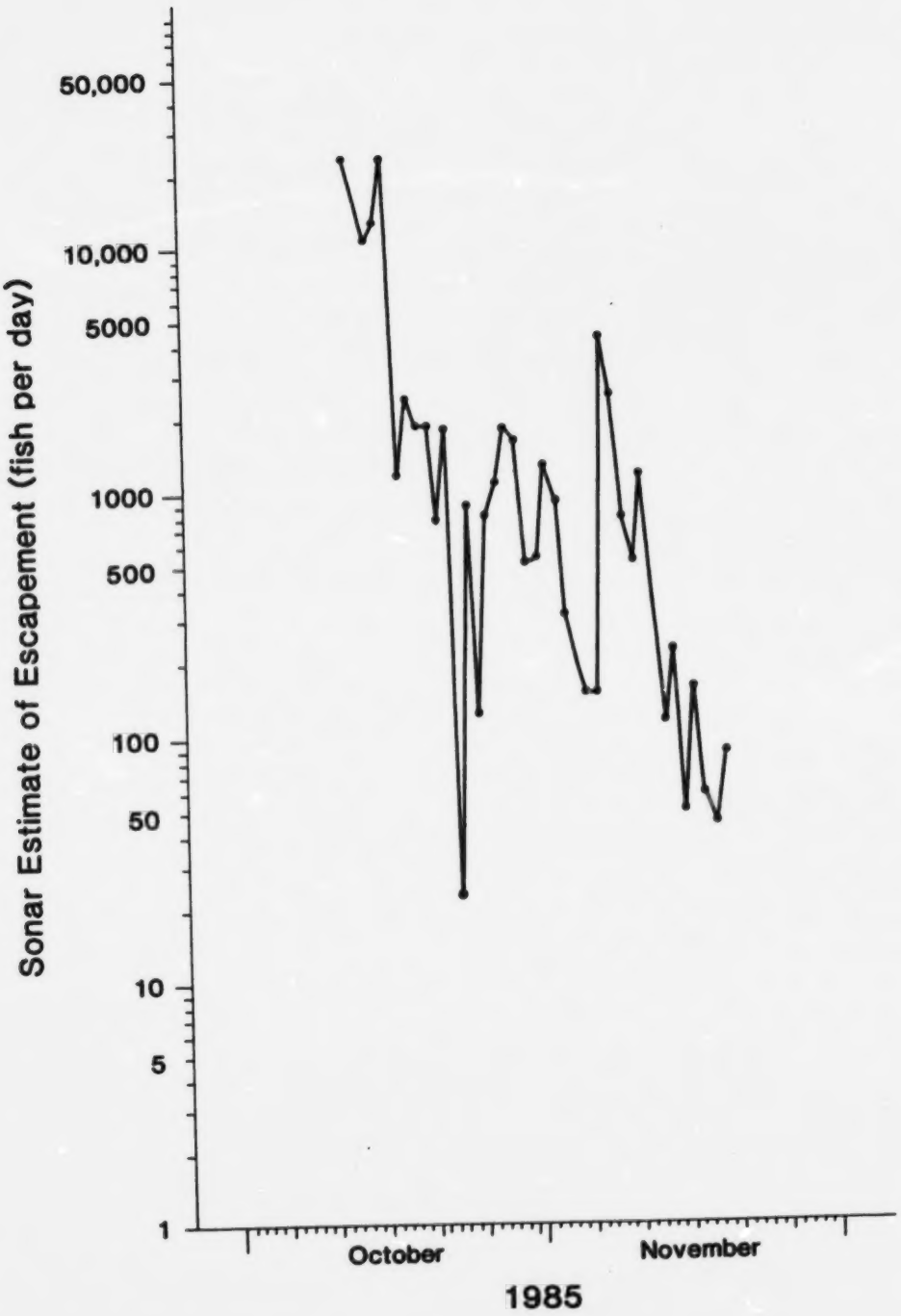

FIGURE 12. Bendix sonar fish counts at the Keogh River counting fence between 12 October and 19 November 1985.

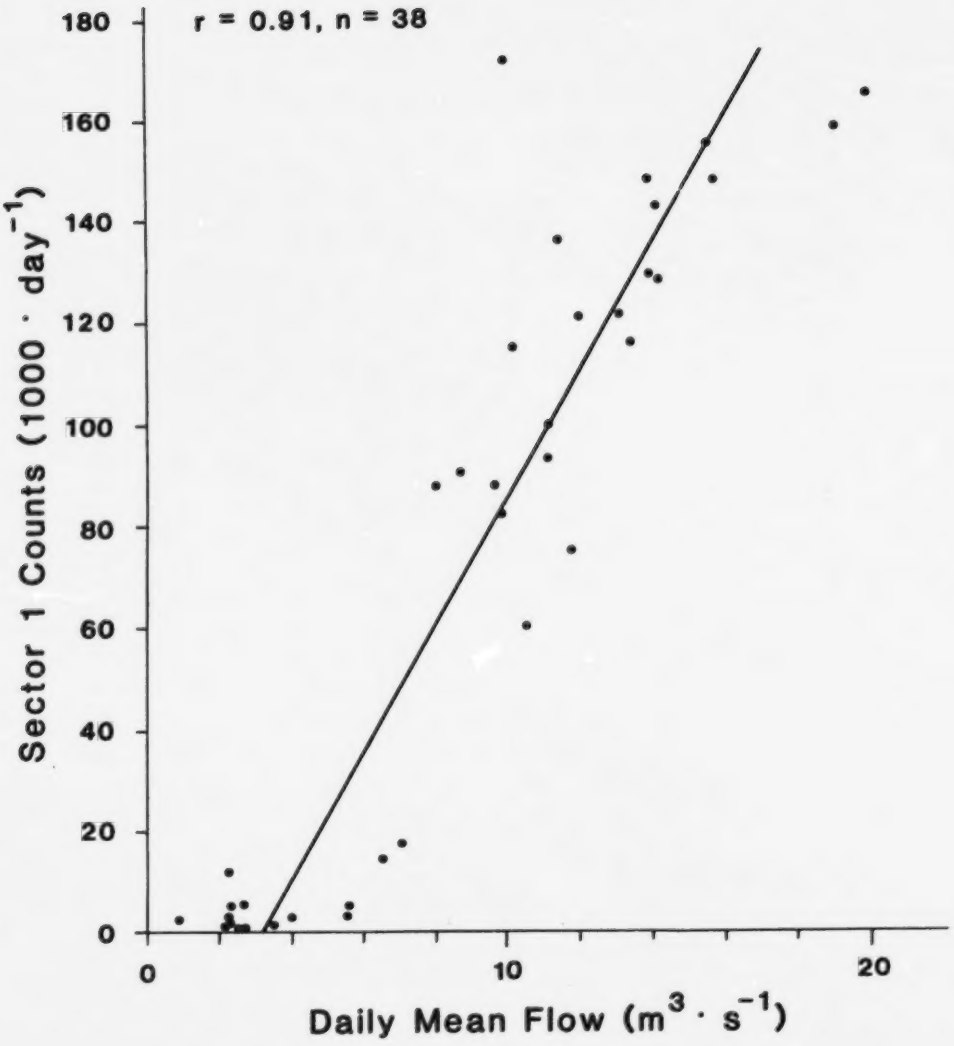

FIGURE 13. The relationship between daily mean discharge and the total number of sonar counts per day in the nearshore sector of the sonar beam. The straight line is the best fit to the data.

TABLE 6. A comparison of the cost, reliability, accuracy, and precision of three methods of enumerating salmon escapements. All labour costs are given in man-days.

	Temporary Counting Fence			Mark – Recapture	Bendix Sonar
Capital costs:					
materials	$3,900			$800	$80,000
fabrication labour	10			–	–
installation labour	15			–	19
removal labour	7			–	5
Operating costs:					
materials	$ 200			$775	$ 50
labour per operating day[a]	2.4			1.7	0.2
Reliability: per cent time usable[b]	93			75	70[c]
	Continuous operation	**3-day interval**	**7-day interval**		
Accuracy: per cent deviation[d] from known for Pinks	–	-27 to +24	-41 to +26	-10 to -1.5	>1000
for Coho	–	-29 to +58	-62 to +200	- 45	
for Chum	–	-25 to +21	-89 to +121	+189	
Precision: Coefficient of Variation for Pinks	–	23.5	20.0	7.6 - 9.0[e]	>12[f]
for Coho	–	43.9	90.7	26 - 65	
for Chum	–	20.6	71.0	26 - 65	

a) actual labour averaged over operating periods between 13 Sept. and 23 Nov.
b) measured over period of temporary fence operation, 13 Sept. to 5 Dec.
c) measured over period of sonar operation, 25 Sept. to 23 Nov.
d) calculated as 100 (N-N)/N
e) approximate calculation from the 95% confidence limits, as
(95% CL - $\hat{N}$) ≈ 2s
f) approximate calculation treating each hourly sector count as a random variable with a standard deviation of $\sqrt{x}$, for x = 25,000

seem difficult to eliminate this source of spurious counts, although some of the placement techniques discussed by King (1984) may help.

We believe that our results represent the first published attempt to calibrate a Bendix sonar fish counter against a known fence-count. It is also one of the few situations in which the sonar operated over the entire river channel that was available for fish passage. The problems which we encountered strongly suggest that calibrations of the Bendix sonar fish counter against known, fence-counted escapements should be repeated before reliance is placed on the sonar counts. It is quite evident that the performance of the instrument is highly dependent on site-specific conditions, and that the right choice of a site for its deployment is imperative if reliable escapement data are to be obtained.

The mark-recapture escapement estimation performed surprisingly well from the point of view of both cost and accuracy (Table 6). The very low capital costs offset the moderately high manpower requirements for tagging (3 person crews) and stream surveys (1 or 2 two person crews). The accuracy and precision of the most appropriate estimate (the Schaefer estimate which omits the recoveries from the fence) were excellent. However, a number of factors improved the performance of the mark-recapture methods. The calculated operating cost is low for several reasons. Firstly, it does not include the additional costs in capturing fish for tagging, which would normally be necessary; these costs would not be great in many situations. Secondly, the abnormally low flows throughout the early part of the salmon runs substantially reduced the costs of the stream surveys by restricting the salmon distribution to a small portion of the watershed. The low flows also may have improved the accuracy of the estimate. Because much of early pink salmon run accumulated in the fence pool, there was good mixing of tagged and untagged fish and of different temporal components of the run. The low waters also made accessible to our surveys all areas of the river channel; during higher flows deep pools and mid-channel areas are less easily censused for carcasses. Low flows also enabled surveys to be conducted during a higher proportion of the time than would usually be possible.

A number of factors are known to bias mark-recapture estimates of population size. Among the most important of these are non-proportional tagging, tag loss, and tag recoveries which are selective by size, sex, or run component (Ricker 1975; Cousens et al. 1982). Although our tagging was not exactly proportional to daily run size, the use of numbered tags allowed recoveries to be stratified by time of tagging and time of recovery. It is interesting to note that the Petersen estimates, which do not stratify in time, gave estimates which were very similar to the more appropriate Schaefer estimates. Non-proportional tagging does not appear to be a real problem in this instance.

We estimate tag loss to occur at about a 5.2% rate. However, because erosion of flesh around spaghetti tags left prominent tag wounds which were easily and accurately recognizable, fish which had lost their tags were readily identifiable and could be included as tag recoveries. Thus, the reduction of the tag ratio from tag loss which produces overestimates of population size was unlikely.

Because females commonly remain in shallower areas around the redds than do the males and because larger fish are more visible, tag recoveries may be selective by sex and size (Cousens et al. 1982). The average size of tagged carcasses recovered was identical to that of the tagged population (mean post orbital length of 415.3 mm for tagged carcasses and 415.1 mm for the tagged population; ns; t-test). Similarly, the sex ratio of the tagged carcasses was the same as that of the tagged population (X^2=0.5; n =3828; ns). Thus, the common sources of bias were not present in our data for pink salmon.

The success of the mark-recapture estimation procedure varied among the three species of salmon in the Keogh. The differences in accuracy and precision of the estimates which were obtained reflect, in part, differences in their biology which makes some species more amenable to the method than others. Pink salmon were caught abundantly at the fence throughout a month long period. We were able to tag 9.9% of the escapement and to recover 22% of the tagged fish. Because of their restricted spatial distribution and their use of relatively shallow spawning areas, pink salmon were easily recovered in abundance. In general, the assumptions of mark-recapture methods (Cousens et al. 1982) did apply to the pink salmon population. Consequently, the good estimates of population size are not surprising given the large number of carcasses (6,459) recovered. Chum salmon similarly seem to be good candidates for mark-recapture estimates of escapement. Their restricted upriver migration, their use of small tributary streams, and their size aid the recovery of tagged carcasses. Although we tagged 16% of the known escapement and recovered 15% of the tagged fish, the small numbers involved reduced the accuracy of the estimate. Mark-recapture methods may be inappropriate for the estimation of coho salmon escapements in the Keogh River because of the difficulty in recovering tags. Although about 15% of the known escapement was tagged, only 3.3% of the tagged animals were recovered as carcasses. Indeed only 2% of the known escapement was found as carcasses (compared to 20% of the pinks and 52% of the chum), and these carcasses were dispersed over 30 km of river. It is not clear where the coho go. Coho spawn in small headwater streams of other areas (Solazzi 1984), and coho were seen in tributaries of the Keogh, West Tributary Creek and O'Connor Creek. They may also utilize the large lakes (Keogh, O'Connor, Misty, Long, Muir) in the headwaters, or tributaries to the lakes. Nevertheless, the small number of tag recoveries and the great effort to obtain them make mark-recapture methods a costly and relatively imprecise technique for estimating coho escapements. Tagging at sites closer to known spawning areas might improve tag recoveries. The censusing of live fish by beach seining or electroshocking rather than recovering carcasses may also improve sample sizes for mark-recapture estimates, although perhaps at the risk of increased mortality among spawning fish.

The temporary counting fence combined moderate capital cost with high reliability and accurate escapement estimates (Table 6). It offered a number of advantages compared to more conventional designs. The temporary fence was operated six weeks beyond the latest historical date of operation of the B.C. Fisheries Branch permanent fence at the same site. It was successfully operated at high flows (over 21.6 $m^3.s^{-1}$ or 760 cfs) during the autumn leaf fall when great amounts of debris were carried in transport. It could be cleaned from shore by a single person at no risk to his safety (however, two person crews were used).

The capital costs cited in Table 6 for the temporary counting fence would be substantially higher elsewhere, since we were able to use the existing trap boxes and sill. The operating costs given in Table 6 represent the actual manpower devoted to fence operations (cleaning, maintenance, fish counting). In other situations, operating costs may be higher since a two person crew must be available 24 h per day, 7 days a week, although the crew may not actually be used. The operation of the temporary fence at high flows requires frequent cleaning of the fence (Fig. 7), as do other fence designs.

Reliability of operation is an important consideration in the choice of a fence design for counting spawning salmon. The duration of the run may be quite brief in some cases (see Fig. 10) so that an inability to operate at a critical period could severely distort the escapement estimate. The extremely rapid increases in discharge in small coastal rivers during rainstorms (Fig. 6) pose a significant risk of fence washout. The temporary fence operated on the Keogh River was operable 93% of the time and was, in fact, operated 84% of the time. Most of the lost operational time occurred as a result of our initial inexperience with the fence under storm conditions; not having personnel continuously present allowed debris build-up on the net to overstress components of the cable suspension system. It is significant, however, that the temporary fence was later operated at higher flows by having a cleaning crew on site 24 h a day. It is also significant that washouts of the fence involved the failure of the cable hardware but not damage to the fence itself. The simple design and construction materials allowed the rapid repair of hardware failures by the field crew. Similarly, a fence constructed largely from seine bunt webbing was easily maintained by inexperienced, untrained field crews. Ease of maintenance could be advantageous in more isolated situations.

Cabled fences have been used to enumerate salmon in B.C. for at least 45 years (see Schaefer 1951). Two major advantages of cabled fences are the ease with which they can be cleaned by briefly submerging the cable, and the ability to protect them from washout by lowering the fence (Tsumura and Hume 1986). In addition to the double cabled design which we describe above, another cabled fence design, designed by Salmonid Enhancement Programme (SEP) engineers, has been tested in Black Creek, French Creek and the Trent River near Courtney, and Lang Creek and Sliammon River near Powell River. The two designs differ in construction and in operational characteristics although both rely upon an overhead cable as the primary support for the fence barrier.

Both designs rely upon the principle that a submerged horizontal screen can sieve large volumes of water without significant clogging, but adapt it to a barrier at low angle to the water surface. The screening surface in the SEP-engineered fence consists of aluminum tubes which are supported by a series of wooden support frames. These frames abut against a wooden sill at the upstream end and their downstream end is suspended from an overhead cable. The aluminum tubes are parallel to the stream flow and are spaced several cm apart to act as a sieve. The angle of the panels can be controlled by the overhead cable although typically the panels are aligned at a shallow angle so that the downstream end is about 0.5 m above the water surface.

The SEP-engineered design offers several innovations which could be adapted to our temporary fence used in the Keogh River, however, both designs have several common problems. Both suffer from the fact that as the down-

stream end of the fence is raised to accommodate higher flows, the effective self-cleaning action of the inclined screened surface is reduced as the angle increases and debris accumulation increases. The problem is perhaps more acute in the SEP-engineered fence which has a smaller sieving surface than our design and whose weight may make impractical a larger surface. As a safe-fail mechanism during high flows, the SEP fence panels can be lowered and the support cables can be readily detached from the panels to prevent major damage. Similarly, in cabled fences such as ours, the cable is lowered to submerge the net and prevent washout. However, in both instances, this requires that a crew be present to decide when to lower the fence. In practice, the SEP design cannot raise the panel higher than the height of the groins at each end, which would restrict its use in rivers which undergo large increases in water level. The nature of the SEP design barrier panel would make damage much more difficult to repair in the field, but it is undeniably stronger than netting. The SEP fence would also be usable at sites which would cause abrasion of a net fence barrier. Both fences could be moved to other sites, but the SEP design should have a longer working life. The cost of a SEP-type fence, including sill and trap box construction, is estimated as about $13,000 for a river the size of the Keogh (M. LaBelle, U.B.C., pers. comm.) which is rather greater than the cost of our temporary fence. In sum, it seems to us that the SEP fence would work well on rivers with moderate flow but that our design may be more usable in rivers which experience irregular high flows.

The fence design used on the Keogh River was a prototype; our experience has suggested a number of modifications which would improve its performance. The main net barrier should be made from the heavier 210/160 twine size knotted netting which is substantially stronger and more abrasion resistant than the 210/42 twine but which costs little more. If the main net is constructed of 210/160 twine, the inner safety net can be discarded. The second overhead cable should be retained, however, but connected to the main net. The main net would then be self-cleaning by raising the upstream cable and submerging the downstream cable, while still maintaining a barrier to fish passage. The flat panel design of the SEP fence could perhaps be adapted to our netting design to reduce debris accumulation, especially at the front corners of the net. Hardware components, which vary greatly in quality and cost, should be of a higher quality to reduce the risk of overstressing the components. Many of the problems associated with the operation of the fence would be reduced by locating it other than in a violent rapid with large boulders; however, this would require a new temporary sill and trapbox. It should be noted that cabled fences of a design similar to ours have been successfully used to enumerate downstream smolt migrations in several coastal rivers (Tsumura and Hume 1986); the design is effective in the appropriate circumstances.

In this study, we have successfully compared and evaluated three separate techniques for enumerating upstream migrating adult salmon. The comparison of enumeration methods at the Keogh River has suggested that fence counts may be the only acceptable technique for enumerating coho if accurate or precise data are required. In contrast, mark-recapture methods may be quite accurate for pink salmon and possibly also for chum salmon escapements. Since counting fences will continue to be required, a comparison of the costs, reliability, accuracy, and precision of different fence designs in the same or nearby rivers which experience similar conditions should be undertaken to improve the

design of inexpensive, portable, reliable fences capable of fishing under highly variable flow conditions. Given the importance of escapement estimates, we feel it is essential that further studies of this type be undertaken. In particular, modifications to our cabled fence should be tested. We also emphasize that comparisons of electronic counters against known escapements from fence counts are required before reliance can be placed on the electronic counters. Many evaluations of sonar fish counters are suspect because of the imprecision of the escapement estimates against which the sonar counts are calibrated. Although the Bendix side-scan sonar proved unsuitable in a small variable flow river, other electronic counters should be evaluated.

The agreement of fence count and mark-recapture estimates of pink and coho salmon escapements and the good precision of the estimates suggest that these methods can be successfully used to provide escapement estimates. Thus, the monitoring of a number of streams in an index stream study is feasible. The escapement data obtained for the Keogh River salmon runs, combined with the extensive historical data on salmonid production within the river are attributes that recommend the site as one of the several streams required for the evaluation of the indexing concept.

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